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Use of Seawater for Fighting Electrical Fires

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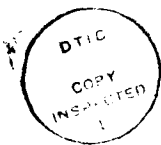
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19. ABSTRACTS (Continued)

from standard Navy fire fighting nozzles presented no shock hazard at distances greater than three feet. By contrast, straight stream patterns required up to 22 feet separations before the zero current point was reached. The safe approach distance varied with the nozzle type, even at the same flow rate. Fresh water streams were shown to require significantly shorter distances than seawater to produce most physiological effects, but the distances required to produce zero current flow were not appreciably different. *DTIC*



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PREFACE

This project was conducted under funding provided by the Naval Research Laboratory (NRL) Contract N00014-84-C-2429 to Hughes Associates, Inc. in support of the Laboratory's Fire Research Program sponsored by the Naval Sea Systems Command (NAVSEASYS COM) Code 56Y5. The purpose of the study was to define the problem of potential electrical shock hazards to personnel when fighting fires involving energized electrical equipment. The report provides the basis from which NAVSEASYS COM may develop and promulgate guidance for fire fighting involving live electrical circuits. A literature search revealed that available data could not be used to predict with confidence the actual hazard to personnel on Navy ships. Specifically, information related to seawater conductivity as applied to standard Navy hose nozzles was lacking.

The authors wish to acknowledge the assistance provided by those who furnished technical guidance and background information necessary to conduct these tests. We are particularly grateful to personnel of the Business and Development Center of Purdue University who furnished both a publication and thesis on the subject. The thesis is based on work conducted by the University's School of Electrical Engineering and Engineering Experiment Station during the period 1909-1936; it formed the basis of tests reported here. The support provided by NAVSEASYS COM electrical engineers in providing design requirements for electrical circuitry and on-site assistance in its installation is appreciated. The enthusiastic support furnished by electricians of the NRL Public Works Department, contract electricians of the Basil Company and fire fighters from NRL's Chesapeake Bay Detachment (CBD) Fire Department in installing the equipment and conducting the tests is gratefully acknowledged.

The conclusions drawn and recommendations made from the results of this study are considered to be not only a basis for promulgating guidance to ships' damage control personnel, but also a potentially useful tool in assessing the degree of personnel hazard associated with incidents involving shipboard electrical fires. The use of equipment similar to the test apparatus would be valuable in providing hands-on training and experience at Navy fire fighting schools.

A recent fire on a Navy ship resulted in considerable damage to electrical equipment which may have been mitigated if fire fighters had not been overly concerned about possible injury or death from electrical shock, due to application of seawater streams to a fire in a cableway. This incident highlights the need to provide adequate guidance to Navy fire fighters regarding electrical shock hazards.

USE OF SEAWATER FOR FIGHTING ELECTRICAL FIRES

INTRODUCTION

Background

There have been several incidents on U.S. Naval ships where reluctance to use seawater hose streams on electrical fires has resulted in considerable damage. This reluctance results from excessively conservative guidance intended to protect damage control personnel from possible injury or death. Current U.S. Navy guidance prohibits use of a straight stream on fires involving energized electrical equipment and limits the use of fog patterns to "last resort" measures. Indeed, accidents resulting from the application of water to electrical sources have occurred, highlighting the need for more definitive guidance for fire fighters on when and what type of water streams should be applied.

By reference [1], The Naval Research Laboratory (NRL) was requested to define the problem of shock hazard relative to the use of seawater hose lines on fires involving energized electrical cables and equipment. This request was a result of the recommendations relating to lessons learned from a major fire which occurred on the USS TATTNALL on January 29, 1984.

As part of this investigation, a literature search was conducted which included publications by the following recognized authorities:

- National Board of Fire Underwriters
(American Insurance Services Group Inc.)
- Factory Mutual Engineering Corporation
- National Fire Protection Association
- Purdue University
- Underwriters Laboratories Inc.
- Naval Research Laboratory
- Nuclear Regulatory Commission

● National Bureau of Standards

The literature search revealed that considerable previous research had been performed in the area of hose stream conductivity. A discussion of the information extracted from the survey is given in Appendix A.

Physiological Effects of Electrical Currents

Research conducted by Underwriters Laboratories Inc. (UL) and cited in The Fire Chief's Handbook [2], indicates that the maximum continuous current to which an individual can be safely subjected is 5 milliamps (mA), and that there is a definite relationship to the length of exposure to electric shock and the effect of the shock. It also states that many authorities consider that a current of 50 mA passing through the human body is the approximate lower limit likely to cause fatalities. In tests conducted at Purdue University and referenced in the Handbook, where the resistance of the human body was assumed to be 5,000 ohms, the effects of various 60 cycle currents are estimated. It is stated that a current of 1 mA will just be felt; 4 to 10 mA, depending on the individual, will cause a sense of pain; 30 mA may cause unconsciousness and a current of 100 mA may be fatal.

More detailed studies by the National Bureau of Standards (NBS) [3] related to a survey of ground fault circuit interrupters in buildings for protection against hazardous shock is in general agreement with previous estimates. The NBS study provides a more quantitative explanation of the cause and effect of electric shock on individuals. The NBS review indicates that the magnitude of current that flows through the body is determined by the potential difference or voltage of the current and the body resistance or other resistances in series with the body. A person's skin provides much of the body resistance. Resistivity of the skin varies with individuals. When dry it may be as high as 100,000 to 300,000 ohms-cm, but when the skin is wet or broken by a cut, the resistivity may be only 1% of this value. NBS further states that a value of 500 ohms is commonly considered to be the minimum resistance of the human body between hands or between other major extremities such as hand and foot. This value is frequently used in estimating shock hazard currents in industrial accidents. The effects of various levels of current on the human body are described as:

- (1) Perception Currents - The level at which alternating current stimulates the nerves as indicated by a slight tingling sensation. The mean

perception current value for men is 1.1 mA at 60 Hz and the mean value for women is 0.7 mA at 60 Hz.

- (2) Reaction Currents - Currents equal to or slightly greater than perception currents that could produce an involuntary reaction.
- (3) Let-go Currents - The maximum current a person can endure and still release the conductor by voluntary muscular control. The maximum uninterrupted, reasonably safe let-go currents are 9 mA for normal men and 6 mA for normal women.
- (4) Currents at Slightly Above "let-go" Levels - Currents at or a little above those at which a person can "let go" of a conductor (but below currents causing ventricular fibrillation - stoppage of heart action and blood circulation) may contract chest muscles and stop breathing during a period of shock. Normal breathing may resume when the current is interrupted. However with prolonged application of current, collapse, asphyxia, unconsciousness and even death may occur in a matter of minutes.
- (5) Currents Causing Ventricular Fibrillation - The human heart rarely recovers from ventricular fibrillation. Experiments which cause stoppage of heart action and blood circulation cannot be conducted on man. However, extrapolation of data from animal experiments indicates that ventricular fibrillation in normal adults is unlikely if shock intensity is less than $116/(T)^{1/2}$ mA, where T is in seconds. These effects are summarized in Fig. 1.

Both perception currents and let-go currents increase considerably as frequency is increased. However, little is known concerning the effect of frequency on fibrillation currents in humans. Studies have shown that the current required to cause fibrillation in dogs at 3,000 Hz is 22 to 28 times that at 60 Hz.

A brief but comprehensive presentation on the effect of electrical shock on individuals was provided by the manufacturer of some of the test equipment used in this program [4]. The effects of both alternating and direct currents are shown as milliamperage ranges within which different individuals may perceive the same physiological effect. This information is reproduced in Table 1 and will be referred to in the discussion of results of this study.

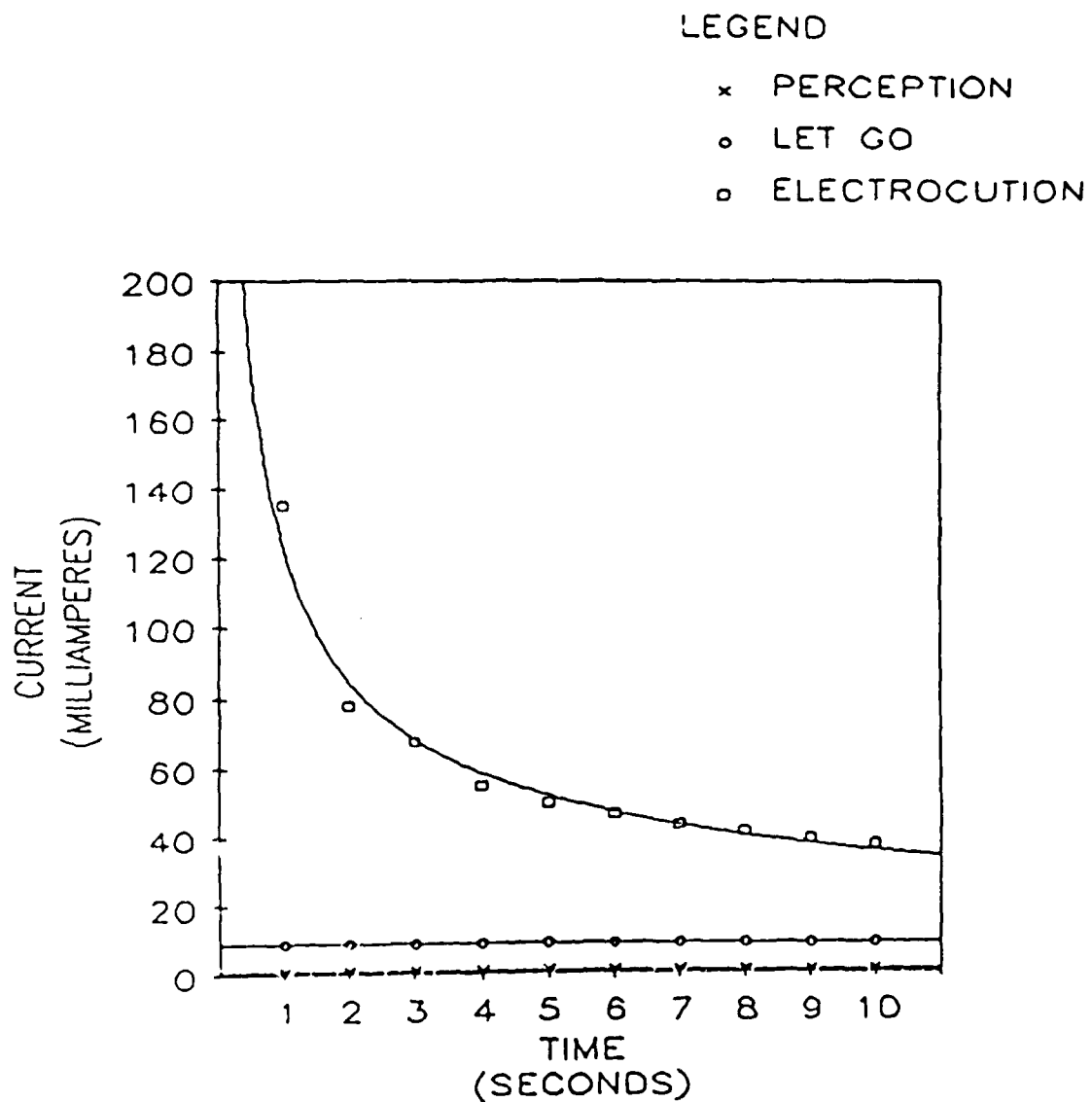


Fig. 1 - Physiological effects of electrical currents
on the human body from studies by
C.F. Dalziel and W.R. Lee [Ref. 21]

TYPES OF TESTS AND ANALYSES

Current and Voltage Tests

The effect of seawater hose streams on potential shock hazard to fire fighters was evaluated by measuring electrical currents at different voltages which would pass through a human body, simulated by a 500 ohm resistor, at various distances between nozzles and an energized target grid (Fig. 2). Although both current and voltage were measured, only the current measurements were used to estimate the degree of shock hazard. Current levels, in milliamperes (mA), can be related to known physiological effects on the body, while the effects of voltage vary considerably among individuals. The electrical tests were made at distance intervals of either one foot or six inches between nozzle and grid. The distance was increased from six inches, for most source voltages, to a point where no current was detected. The six-inch criterion for closest distance was later changed to that distance where either 500 volts or 500 milliamps were detected, in order to avoid instrument damage (from the highest voltage source).

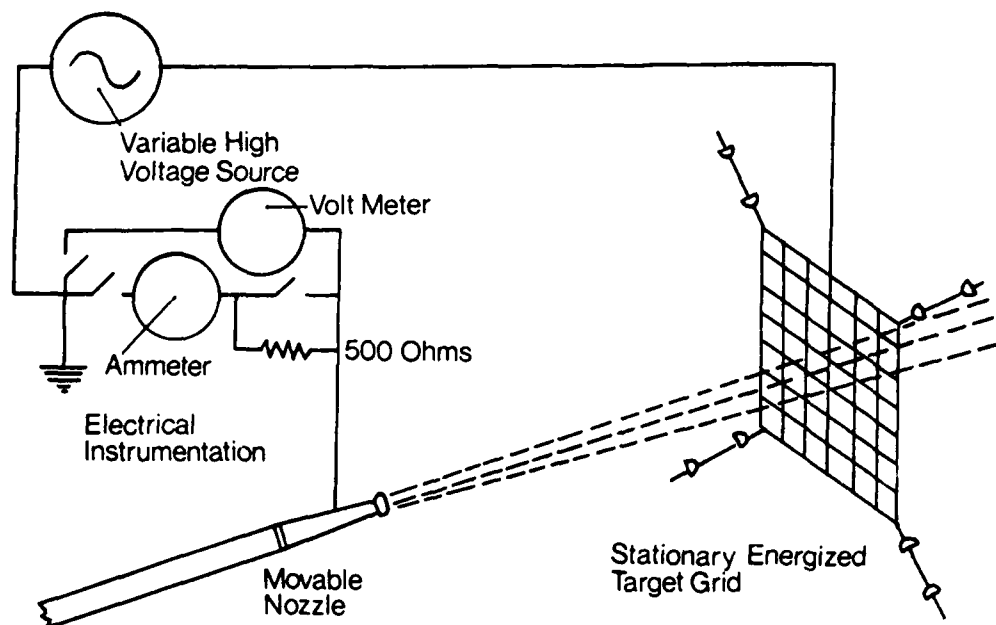


Fig. 2 - Test equipment diagram

In addition to electrical measurements through the 500 ohm resistor, electrical tests were performed at each distance using a bypass shunt around the resistor to demonstrate the effect of lower body resistances.

Conductivity Tests

Although most of the tests were conducted with synthetic seawater, tests were run with fresh water as a comparison. Frequent electrical conductivity tests were performed on the synthetic seawater to ensure that the electrolyte concentration remained constant throughout the testing program.

A Markson Model 10 conductivity meter was calibrated daily, using potassium chloride solutions with known conductivity values, to assure its accuracy. The meter was equipped with a temperature compensating device to correct errors in the measurements caused by solution temperatures other than 25°C (77°F). Actual hose stream conductivity values varied with changes in the synthetic seawater temperatures.

Flow Rate Measurements

The flow rates of the nozzles were measured using fresh water dispensed at 30 psi and 100 psi nozzle pressures. A previously calibrated in-line, turbine type flow meter equipped with a digital read-out device was employed. Flow rates for the nozzles tested are shown in Table 2.

Nozzles Tested

The three nozzles and respective test conditions requested by the Naval Sea Systems Command (NAVSEASYS COM) in reference [1] for evaluation were as follows:

- (1) a 1-1/2 in., 95 gpm, Navy All Purpose Nozzle conforming to Type II (combination spray and stream) of Military Specification MIL-N-12314 using seawater at 30 and 100 psi nozzle pressures with both the straight stream and fog pattern.
- (2) a 1-1/2 in., 125 gpm, Aqueous Film Forming Foam (AFFF) Nozzle conforming to Type I (horseshoe handle operated) of Military Specification MIL-N-24408 using seawater at 30 and 100 psi nozzle pressures with straight stream, narrow fog (30°) and wide fog (90°) patterns.
- (3) a 1-1/2 in., 95 gpm, AFFF nozzle conforming to Type II (pistol grip handle, trigger operated) of

Military Specification MIL-N-24408 using seawater with the straight stream, narrow fog (30°) and wide fog (90°) patterns.

Subsequent Tests

Proposed Type III, 30 GPM Nozzle

After completion of the tests, and review of preliminary results, NAVSEASYS COM requested similar conductivity testing of a fourth nozzle which is being considered for inclusion in MIL-N-24408. The proposed new nozzle will be identified in the specification as a 3/4 in., 30 gpm, Type III (also to be horseshoe handle operated as is currently required by the specification for 1-1/2 in. and 2-1/2 in. Type I nozzles). The new nozzle is to be used on submarines with fresh water and on surface ships with fresh water, seawater or AFFF (6% AFFF concentrate + 94% seawater). Accordingly, the new nozzle was tested for electrical conductivity characteristics with seawater and fresh water using all available shipboard voltage sources (120 dc and ac to 4160 ac) as well as with AFFF at 440 volts ac only. The new nozzle, when made to proposed specification requirements, will be fabricated from brass or bronze alloys and have only narrow fog (30°) and wide fog (90°) patterns with no straight stream option available. However, the prototype model furnished by the manufacturer (Akron Brass Co.) was supplied with a straight stream option as well as the fog patterns. All three patterns were evaluated for conductivity characteristics for comparison with the three standard nozzles originally tested.

Feecon Dual Agent Nozzle, 95 GPM

A recent effort to reduce the physical effort involved in operating twinned agent (PKP/AFFF) hand lines to accommodate female fire fighters has resulted in the evaluation of a commercial dual agent nozzle manufactured by the Feecon Corporation. Since the Feecon nozzle shows promise of reducing the strength requirement, NAVSEASYS COM personnel requested that it also be evaluated for hose stream electrical conductivity characteristics. It was subsequently evaluated with the same source voltages and water quality (fresh water and seawater) applied to the proposed Type III nozzle discussed above.

Portable AFFF Extinguisher

Portable AFFF extinguishers currently being supplied to submarines are normally charged with 2-1/2 gal of a 10% AFFF in fresh water premixed solution. It was suggested by NAVSEASYS COM personnel that these small portable extinguishers when charged with fresh water might be useful

in combating small electrical fires on surface ships and submarines. An extinguisher manufactured by the Amerex Corporation was adapted to the NRL Chesapeake Bay Detachment (CBD) test apparatus and evaluated for hose stream conductivity characteristics with fresh water and AFFF premix solutions using a source voltage of 440 ac.

EXPERIMENTAL PROCEDURES

Conditions

Source voltages were selected to simulate the worst case shipboard conditions under which Navy fire fighters could be expected to combat fires involving energized electrical equipment.

Source Voltages

These conditions included the use of source voltages (120 dc, 120 ac, 440 ac, 4160 ac) available on Navy ships as requested by reference [1]. In addition, a 2,430 volt ac source was evaluated. This 2,430 volt potential is the probable voltage difference between a power carrying conductor and the ships hull. The full 4,160 volt potential from these systems would result only when a line conductor is inadvertently grounded to the ships hull. A 220 volt source also was included because it represents a commonly available potential in shore facilities where seawater may be used for fire fighting.

Test Apparatus

The basic equipment layout, as shown in Fig. 2, provided a means of directing hose streams on an electrically energized target. Electrical circuits and instrumentation permitted measuring voltage and current levels which would be experienced by a fire fighter holding the nozzle. A more detailed description of the components identified in the diagrams is as follows:

- a. The variable high voltage source consisted of a transformer substation which was capable of supplying all of the voltages required for the tests. A photograph of the substation is shown in Fig. 3.
- b. The stationary energized target grid was fabricated from 1/2 in. mesh copper screen attached to a bronze channel frame measuring 2-1/2 ft x 2-1/2 ft. The grid was mounted in a vertical position between 2 wooden posts by 4 wire cables attached to each corner of the frame and insulated from ground

by means of two 5,000 volt ceramic insulators attached to each of the 4 cables. Electrical energy was supplied to the screen by wiring to the appropriate transformer tap in the substation for the source voltage to be evaluated.

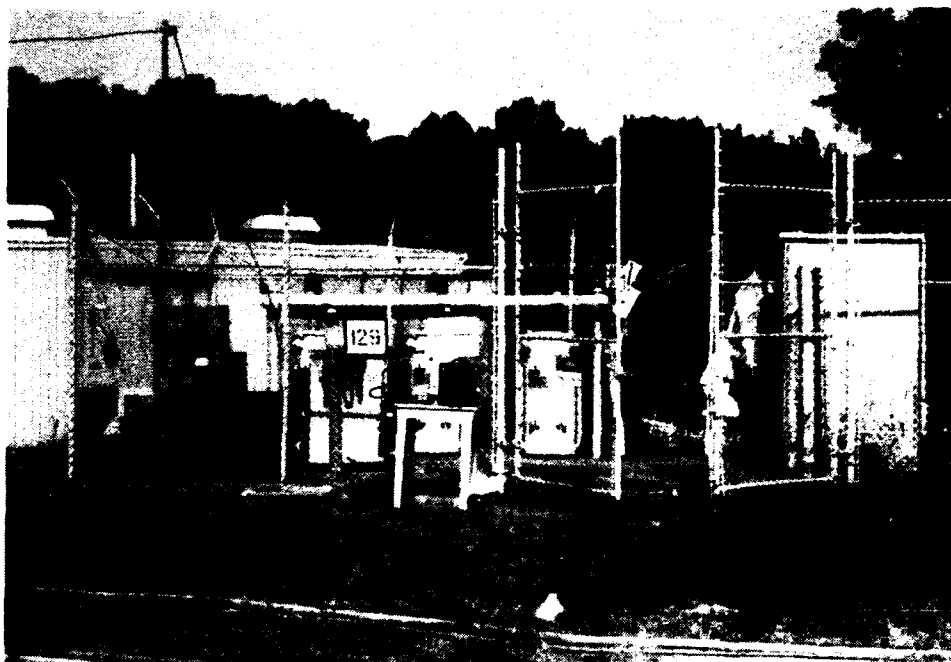


Fig. 3 - Transformer substation used to supply various source voltages

- c. A movable nozzle was attached to a ball and socket type hose control device which was mounted on a rubber tired cart at a height centered on the vertical grid. This arrangement permitted an easy means of varying the stream distance and directing the stream onto the grid. The control device was equipped with a pressure gauge to monitor the nozzle pressure for each test. The cart mounted nozzle positioned near the stationary grid is shown in the in Fig. 4. The large metal structure shown behind the grid served as a backstop and catch basin for the seawater hose streams. The retained seawater was recycled by pumping back to the 450 gal storage tank shown in Fig. 5. This tank then supplied seawater to the fire hose and nozzle by a gasoline engine powered portable fire pump also shown in Fig. 5. Figure 6 is a photograph of the nozzles tested.



Fig. 4 - Nozzle mounted on a movable cart directing hose stream on a charged electrical grid

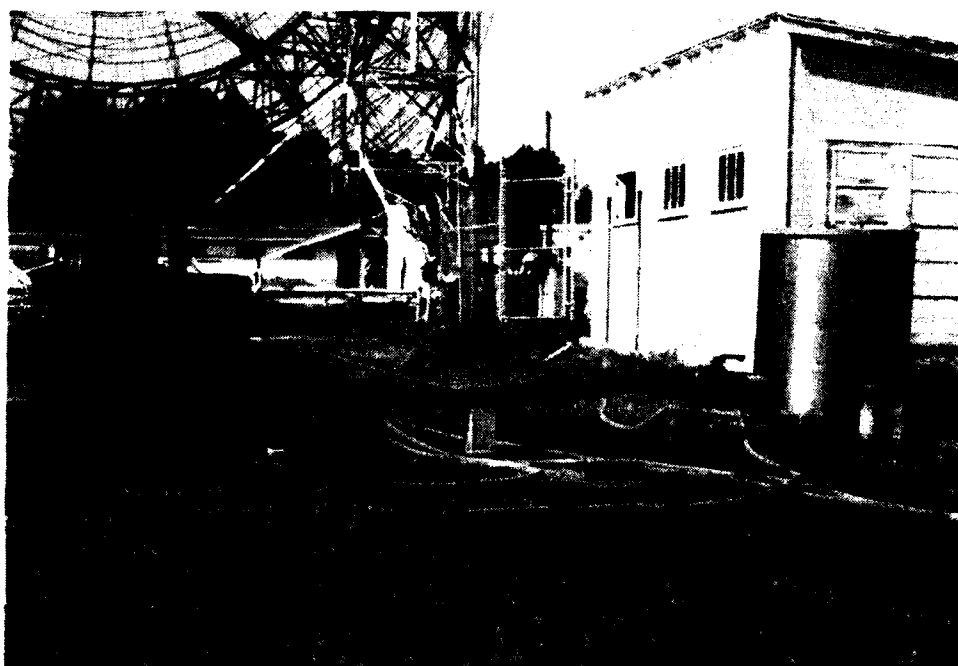


Fig. 5 - Seawater storage tank and portable fire pump used to supply hose streams

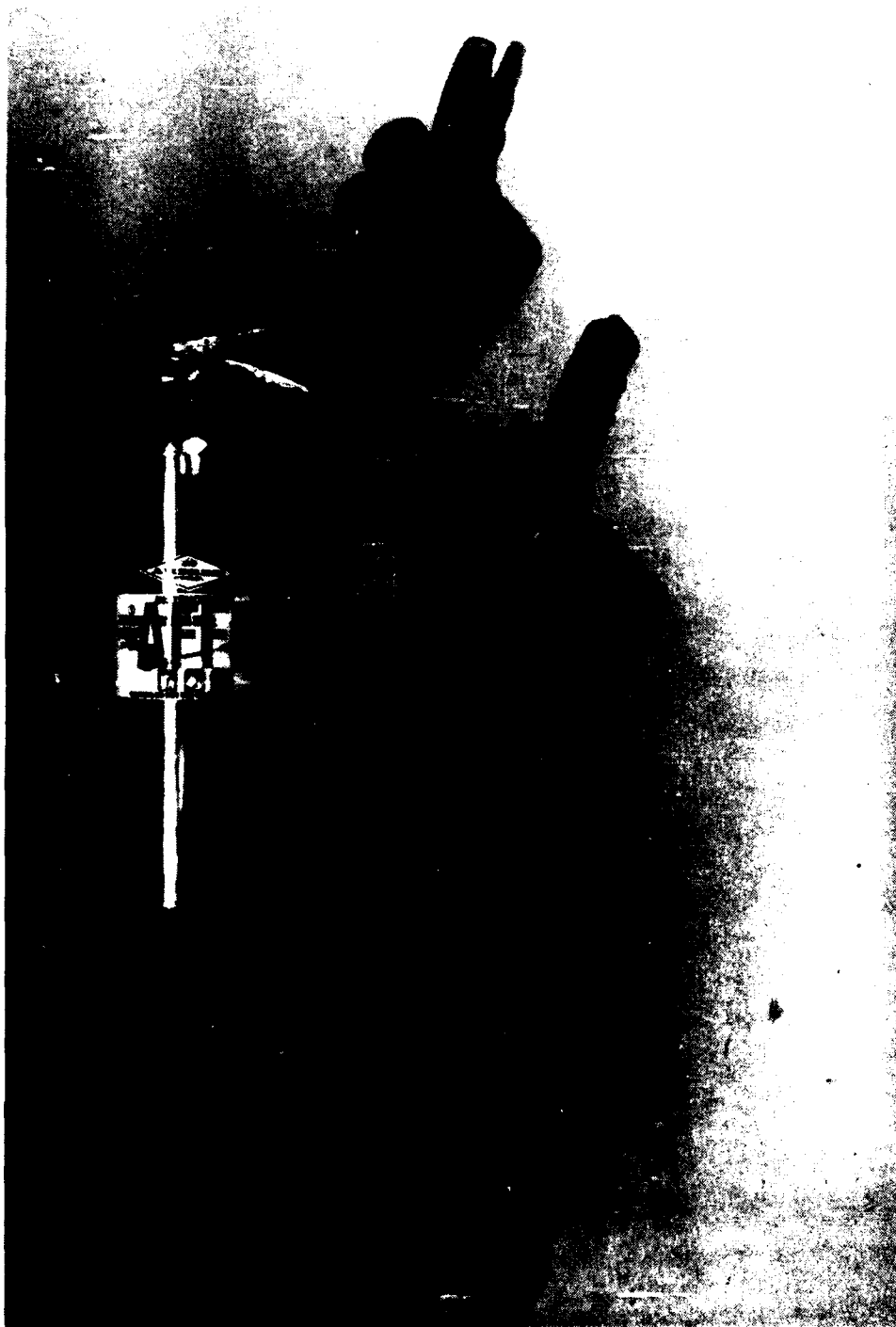


Fig. 6 - Nozzles tested: top, portable AFFF extinguisher;
bottom, left to right, Navy All Purpose nozzle, Type I 125 gpm nozzle,
Type II 95 gpm nozzle, Proposed Type III 30 gpm nozzle, Feecon Dual Agent nozzle

- d. The electrical instrumentation consisted of appropriate voltmeters and ammeters. The recording voltmeter and digital milliammeter used to measure the voltage and current through or by-passing the 500 ohm resistor are shown with the test resistor in the photograph in Fig. 7. Other meters were used to monitor source voltages and currents at appropriate locations inside the transformer substation containment area. The recording voltmeter was replaced by a conventional digital meter when its capacity was exceeded by source voltages above 220 volts.

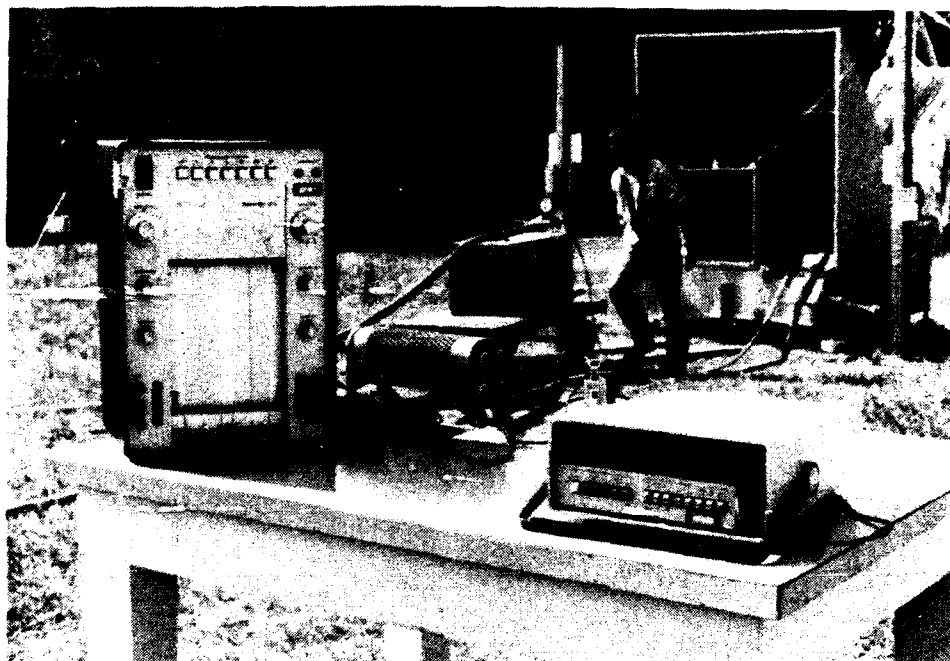


Fig. 7 - Recording volt meter, 500 ohm test resistor and milliammeter used for electrical measurements

Test Procedures

After verifying that the screen was not electrically energized, the cart mounted hose nozzle was located at a convenient distance from the screen. The hose stream flow was then initiated by starting the pump engine and adjusting its speed to obtain the desired nozzle pressure (either 30 or 100 psi). The nozzle position was then adjusted, if necessary, to assure contact of the stream with the grid target. After flow and position of the device were established, operators moved back to a safe distance and the grid was energized with the source voltage. Electrical measurements were then taken of the source voltage and of

both the voltage and current from the nozzle to ground. The current was measured both with and without the 500 ohm resistor in the circuit by means of a switch installed for that purpose. This procedure was then repeated after moving the cart in one foot increments away from the target until the closest distance for zero current flow between nozzle and grid was established. The cart was then advanced toward the target in one foot or six inch increments, repeating the electrical measurements at each distance until the nozzle was either at a position of six inches from the target, or at the position at which the electrical measurements indicated the voltmeter or milliammeter capacity would be exceeded by closer proximity. Attempts to limit the current drawn through the meter to one ampere (1,000 mA) by positioning the cart were not always successful. This criterion for limiting the advance of the cart was changed for the 4,160 volt tests to either a maximum voltage of 500 volts or maximum current of 500 milliamps. Because of the relatively low conductance of fog patterns as compared to straight streams, particular care had to be exercised to avoid damaging the instruments when the cart was in close proximity to the screen. In many cases, no current was detected with fog patterns at a distance of 6 inches between nozzle and grid.

OBSERVATIONS AND DISCUSSION

Electrical Measurements

Test data for both current and voltage measurements for seawater streams with each combination of nozzle, hose stream pattern, nozzle pressure and electrical resistance are shown in Tables 3 through 18. The conductivity of the seawater was 58,000 microsiemens/cm. Similar data for a single test using fresh water, having a conductivity of 370 microsiemens/cm, with the Type I nozzle are shown in Table 19 for comparison. The straight stream seawater data are presented graphically in Figs. 8 through 13. A graph comparing the test using fresh water with a test using seawater is shown in Fig. 14. The data in Figs. 8 through 14 show that the nozzle current falls off rather sharply with distance from the target grid and that, for a given distance, the current increases rapidly with the target voltage. As shown in the tables, there are insufficient data points to plot meaningful curves for the fog patterns because the nozzle must be very close to the charged grid to detect more than a zero current.

A review of the straight stream data reveals that the point of zero current flow through 500 ohm resistance ranged from 6-1/2 ft for the Navy All Purpose Nozzle (NAP) at 120 V ac or dc, to 22 ft for the Type I nozzle at 2,430 V ac. Both of these distances were recorded at 100 psi nozzle pressures. The points of zero current flow through a

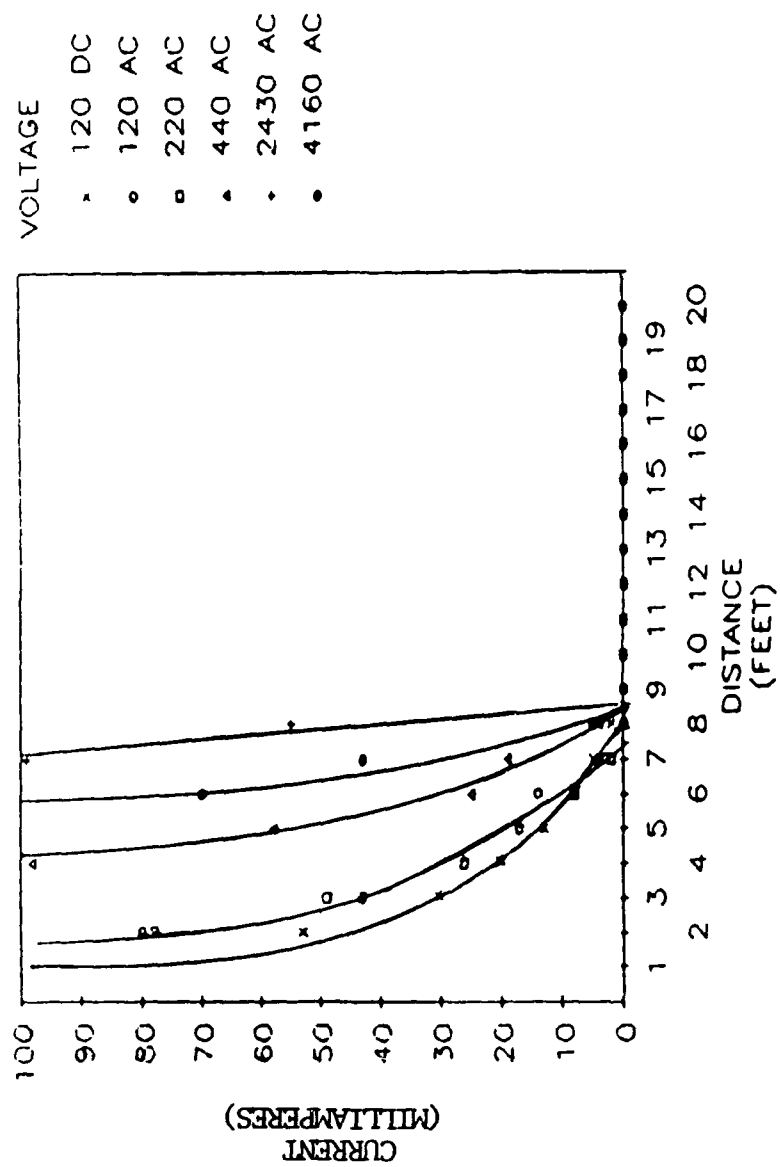


Fig. 8 - Straight stream nozzle currents through 500 ohm resistor, Navy All Purpose nozzle, 30 psi nozzle pressure, seawater

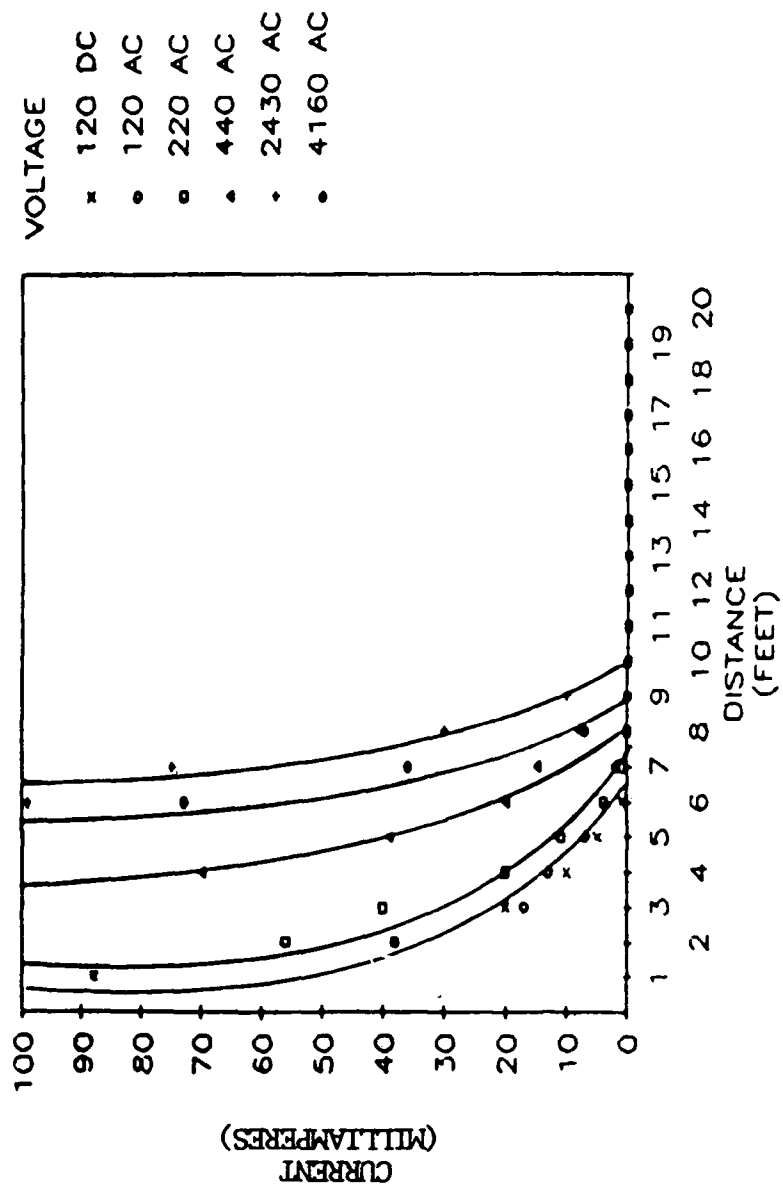


Fig. 9 - Straight stream nozzle currents: Navy all purpose nozzle, 100 psi nozzle pressure, seawater

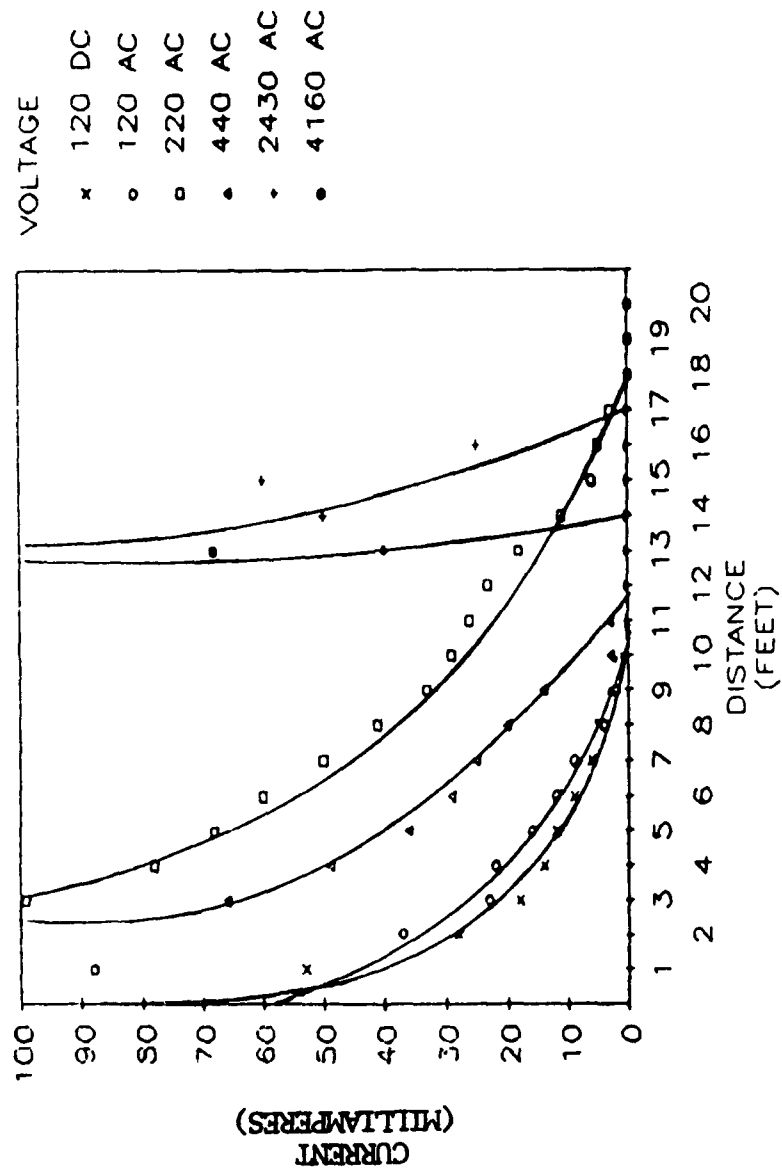


Fig. 10 - Straight stream nozzle currents: Type I 125 gpm nozzle, 30 psi nozzle pressure, seawater

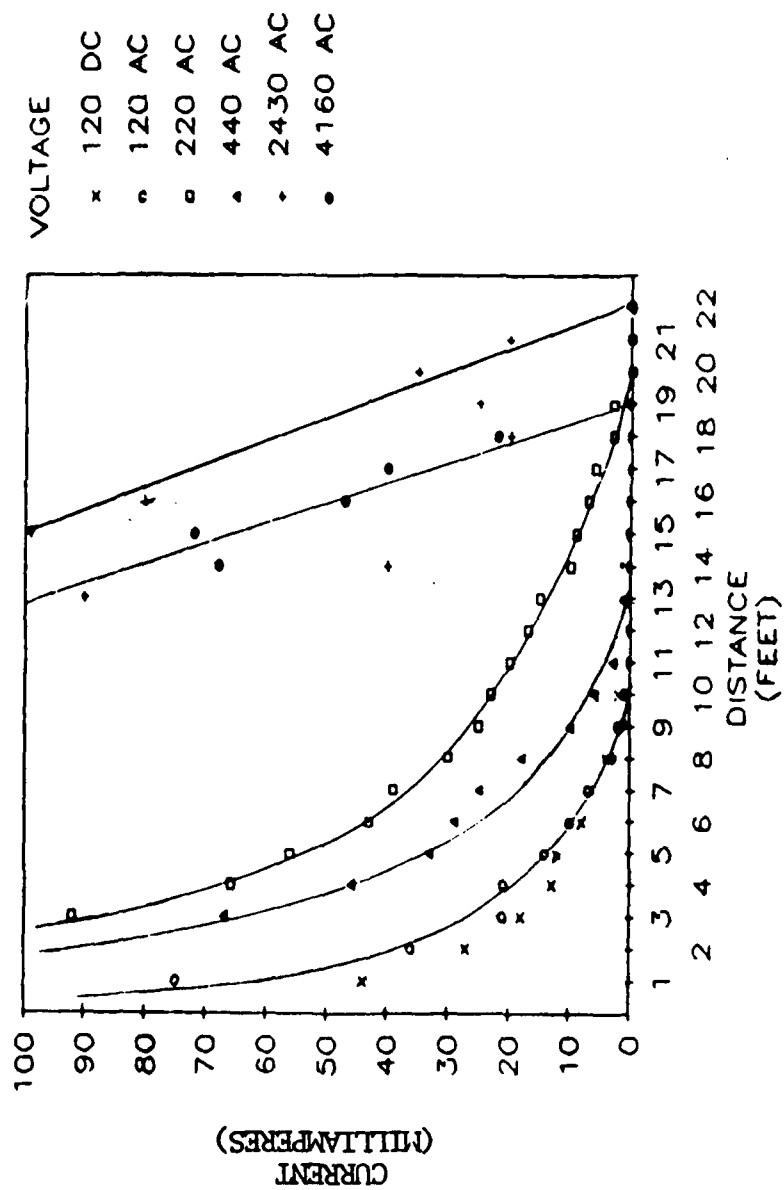


Fig. 11 - Straight stream nozzle currents: Type I 125 gpm nozzle, 100 psi nozzle pressure, seawater

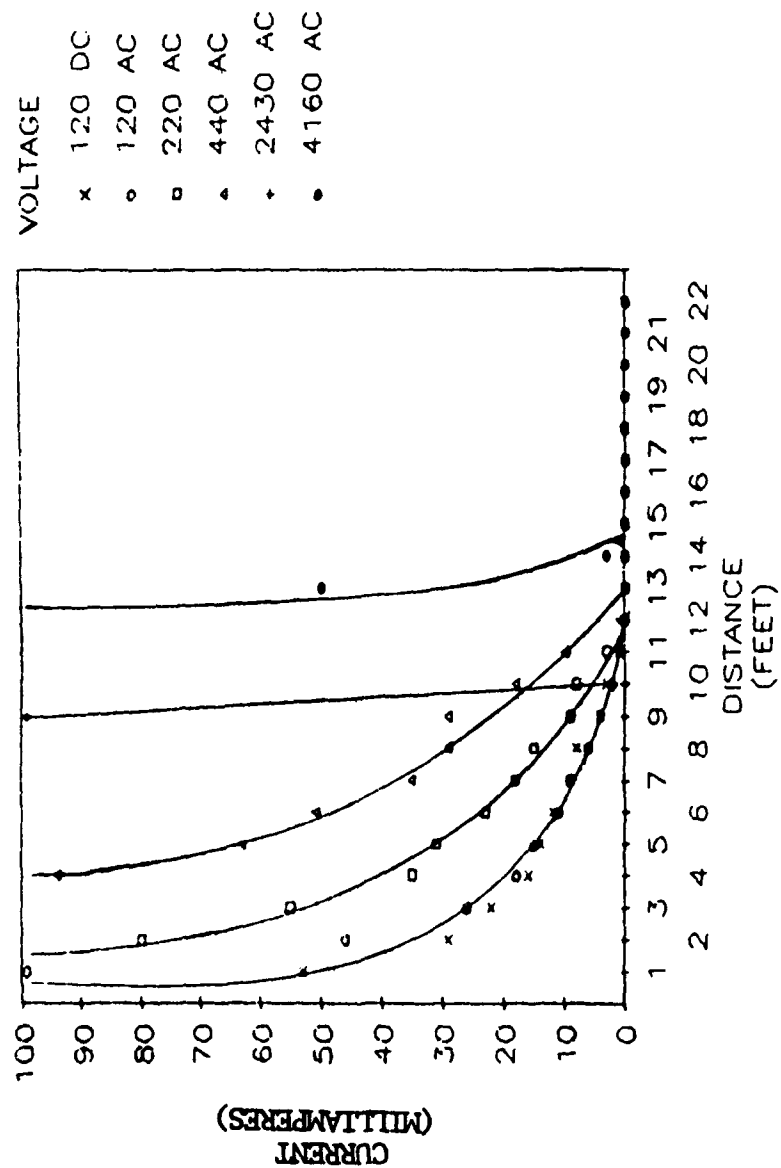


Fig. 12 - Straight stream nozzle currents: Type II 95 gpm nozzle, (trigger operated), 30 psi nozzle pressure, seawater

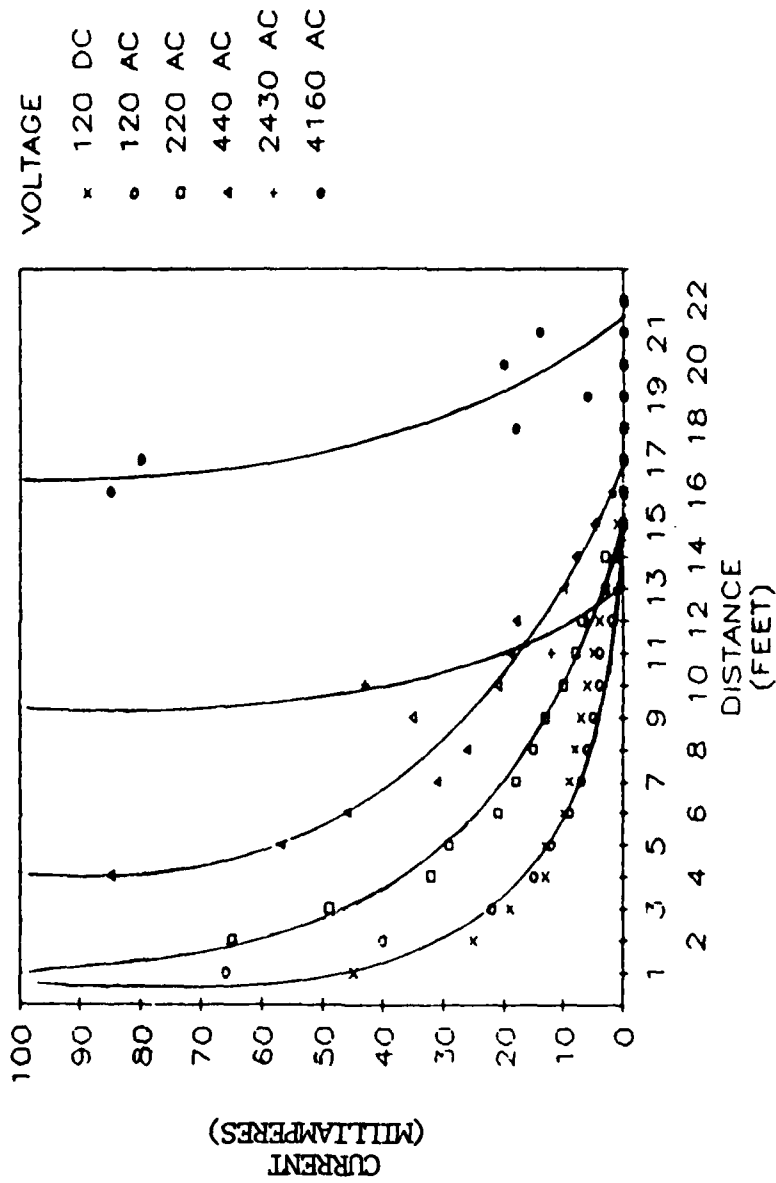


Fig. 13 - Straight stream nozzle currents: Type II 95 gpm nozzle, (trigger operated), 100 psi nozzle pressure, seawater

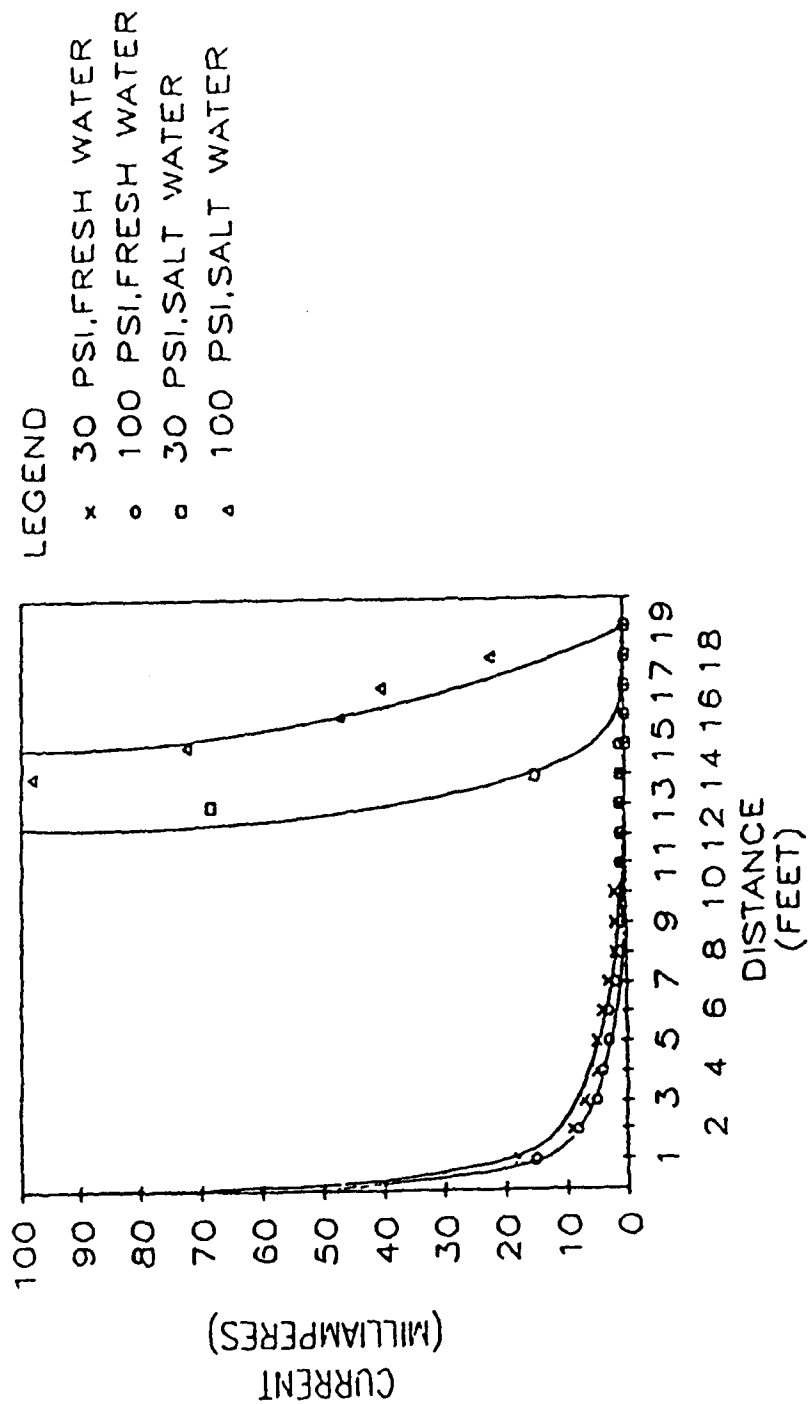


Fig. 14 - Comparison of straight stream nozzle currents for fresh and seawater:
Type I nozzle, 4160 volt ac source

resistance of 500 ohms for the All Purpose Nozzle and for MIL-N-24408 Types I and II nozzles are summarized in Table 20. The data for the distances at which zero current was detected for all nozzles and stream patterns at each source voltage are also presented graphically in Figs. 15 through 20. These data show the zero current distances for the Navy All Purpose nozzles using the straight stream pattern are consistently lower, usually about half of the corresponding distances for either the Type I or Type II nozzles. Also the zero current distances for the Navy All Purpose Nozzle are virtually independent of nozzle pressure or source voltage, whereas the distances for the Type I and Type II nozzles increase with voltage and, to a lesser extent, with nozzle pressure. The maximum zero current distance recorded in these trials for a straight stream is 22 ft for the Type II nozzle at 2430 V. Under the same conditions, the maximum zero current distance for the Navy All Purpose Nozzle is 10 ft.

When fog patterns are used, the zero current distances for the Navy All Purpose nozzle are consistently low (0.5 ft), whereas both Type I and Type II show a slight increase with source voltage, the maximum being only 3 ft at 4160 V for the Type II nozzle.

As expected, the 30° fog patterns for the Type I and Type II nozzles show greater zero current distances than the 90° patterns; however, nozzle pressure does not appear to be a factor when fog patterns are used.

However, the data in Table 20 do reveal some inconsistencies, most of which could be attributed to the fact that the tests were conducted outdoors as opposed to in a controlled laboratory environment. For example, for some nozzles, increasing the source voltage did not result in an increase in distance to observe zero current flow. This apparent anomaly may have been the result of uncontrolled variables such as the effect of wind on hose stream geometry (causing solid streams to break into relatively nonconductive spray patterns) or by fluctuations in the current from the transformer to the energized target. The largest discrepancy of this type occurred with the Type I nozzle at 100 psi pressure where the zero current distance for 220 volts is 19 ft, but at 440 volts it is only 12-1/2 ft; a decrease of 6-1/2 ft instead of an anticipated increase in distance at the higher voltage. This anomaly occurred in four other cases. However, the discrepancies were less severe, ranging from 1 ft to 3 ft in the "wrong" direction. Although the cause of this anomaly is not known, its occurrence indicates a need to estimate "safe" distances with some degree of caution. It is therefore prudent to add a margin of safety to the maximum distance for zero current flow in establishing guidance for fire fighters.

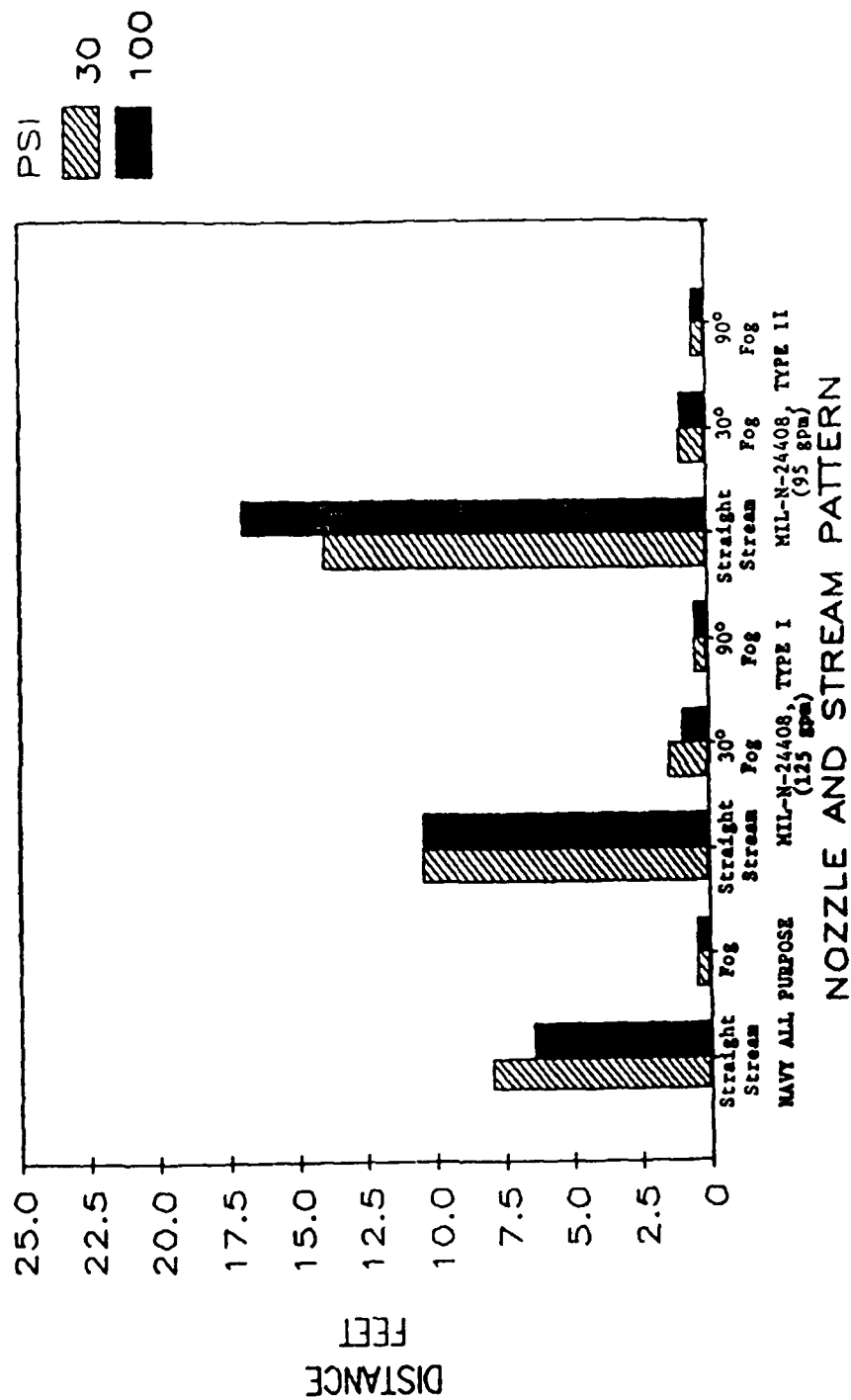


Fig. 15 - Nozzle stream distance to detect zero current,
120 dc source voltage

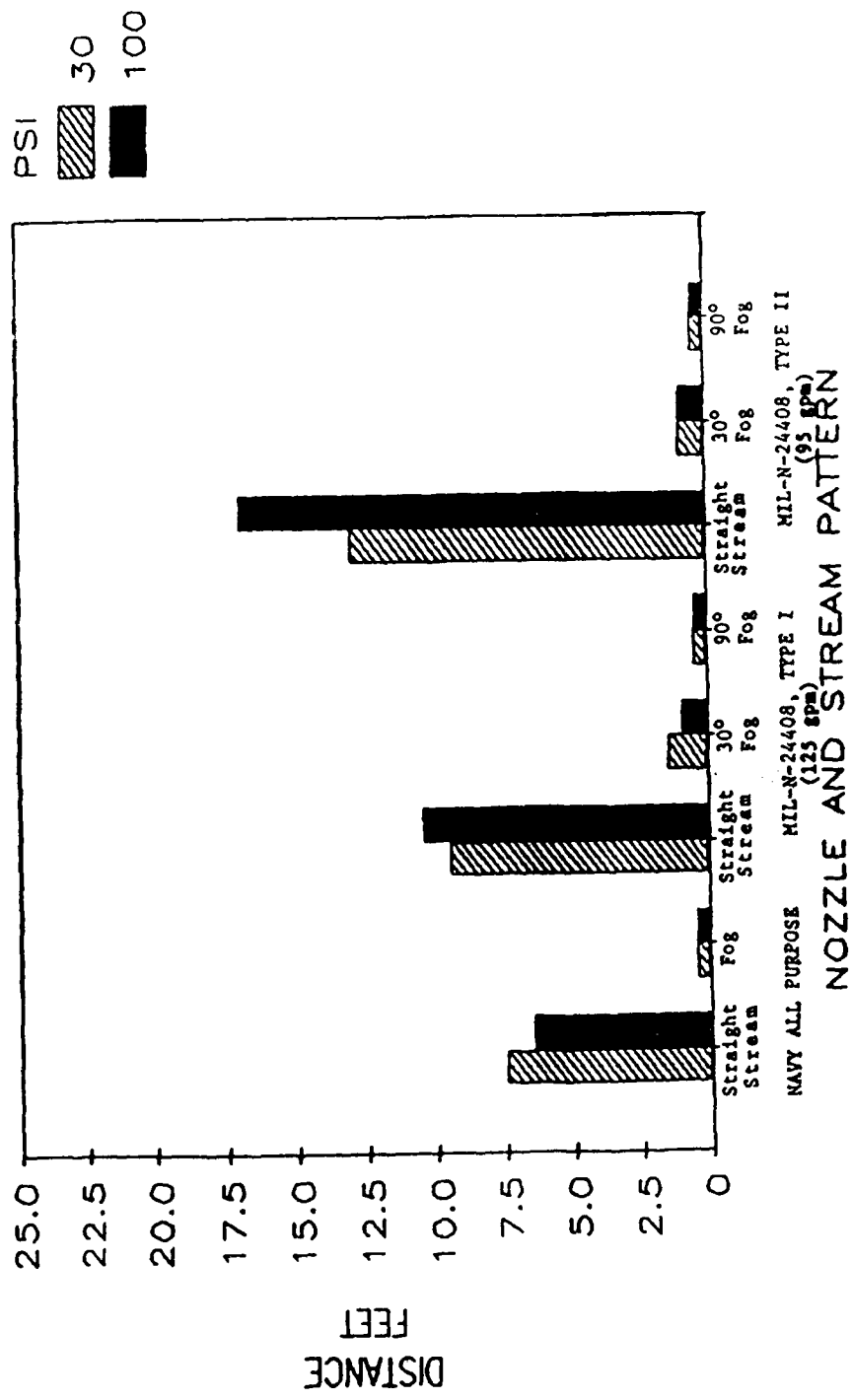


Fig. 16 - Nozzle stream distance to detect zero current,
120 ac source voltage

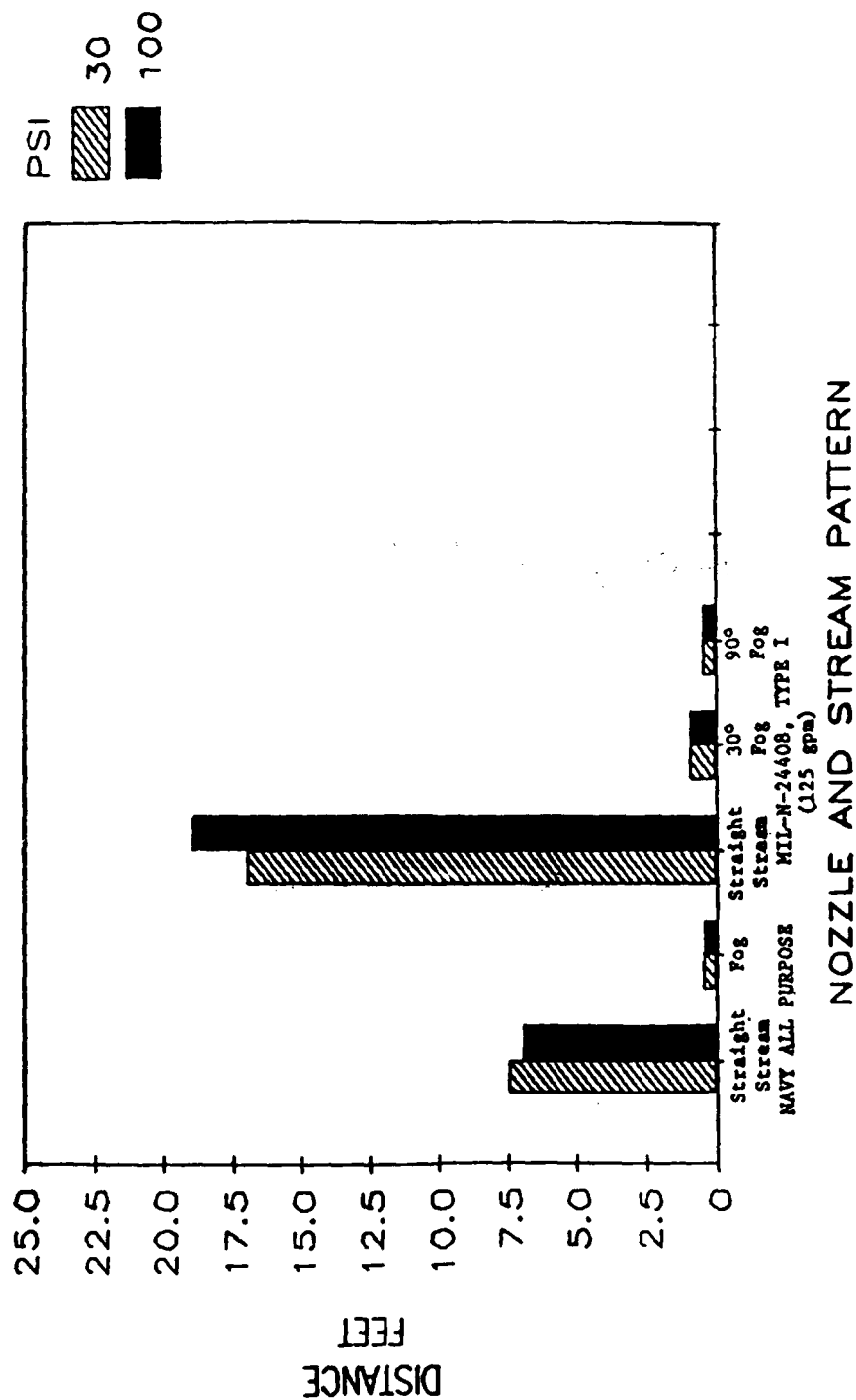


Fig. 17 - Nozzle stream distance to detect zero current,
220 ac source voltage

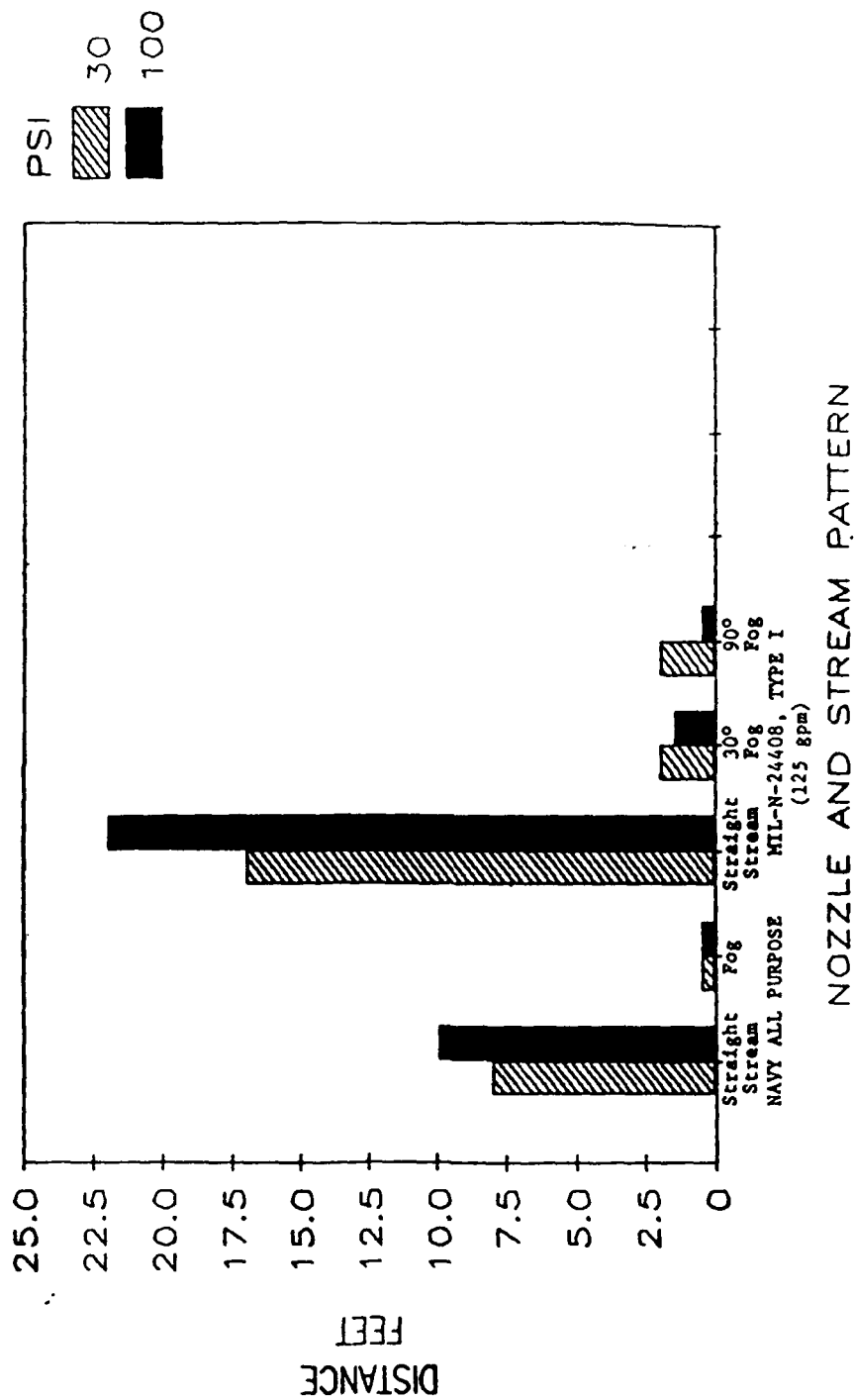


Fig. 19 - Nozzle stream distance to detect zero current,
2440 ac source voltage

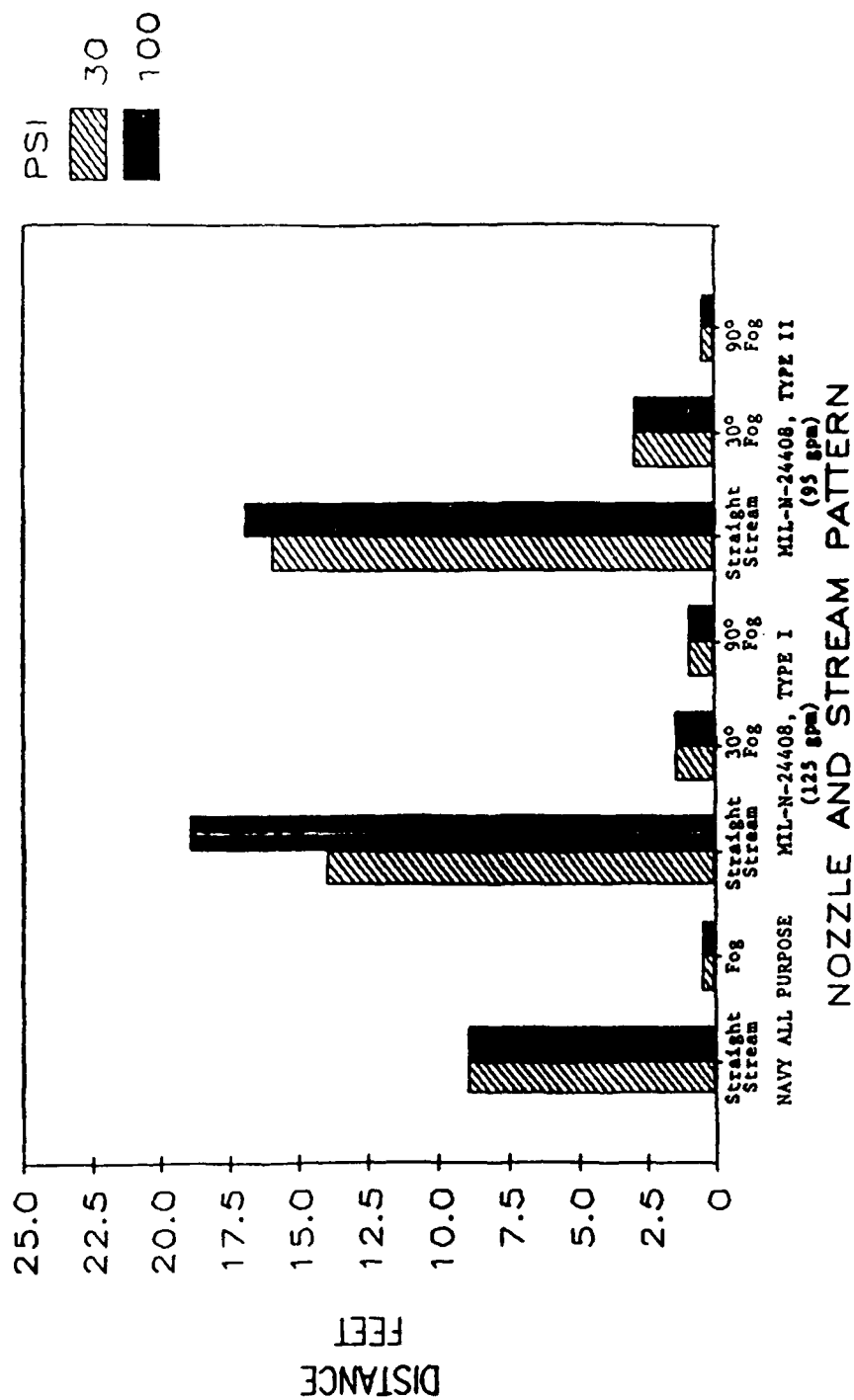


Fig. 20 - Nozzle stream distance to detect zero current, 4160 ac source voltage

The levels of current above the zero point are also of interest since they can be related to known physiological effects. In that regard, it is useful to demonstrate the range of distances at which each of the nozzles tested would produce:

Perception Level Currents which can be detected as a slight warmth in the palm of the hand (0 to 4 mA dc) or a mild tingling sensation (0 to 1 mA ac);

Surprise Level Currents (1-4 mA ac or 4-15 mA dc) resulting in involuntary muscle spasms which may cause an accident;

Reflex Action Level Currents (4-21 mA ac or 15-80 mA dc) which contract the hand muscles to the point where the victim has no control. This could "freeze" the victim to the source long enough to cause lung or heart stoppage.

The probable effects of electric shock at higher current levels which result in muscular inhibition, respiratory block and ventricular fibrillation (usually fatal), are shown in Table 1.

The distance at which physiological effects would be experienced by a fire fighter having a body resistance of 500 ohms while approaching energized electrical devices with a seawater hose stream, can be determined by comparing the current value to produce these effects in Table 1 to the current-distance curves in Figs. 8 through 13. For example, involuntary, reflex action would occur when a stream from the Navy All Purpose nozzle is directed at a 120 V ac source from a distance of as little as 4-1/2 ft (Fig. 8). It should be noted when making these comparisons that the distance from the point where zero current is detected to that where injury would result is often quite short. It is less than 1 ft using the fog pattern with the 4,160 or 2,440 volt sources, but increases to as much as 10 ft for straight stream patterns with the 120 volt source.

Since fire fighters may not always be aware of the level of voltage involved in the energized device, the greatest distance where zero current was detected appears to be the best criterion for establishing safe separation distances. It is apparent from Table 20 that the greatest distance from the source for all the nozzles evaluated is 22 ft for straight stream patterns (Type I, 125 gpm nozzle at 100 psi) and 3 ft for fog patterns (Type II, 95 gpm nozzle at 30 and 100 psi). The addition of a safety margin in the recommended stand-off distances would be prudent.

Other Observations

Fresh Water Test

The results of a single test using fresh water instead of seawater with the Type I nozzle on straight stream and fog at 30 psi and 100 psi nozzle pressures against the 4,160 volt source are tabulated in Table 19. The data for the straight stream pattern are shown diagrammatically in Fig. 14. It graphically illustrates that fresh water is considerably less hazardous than seawater due to its lower conductivity. However, the distance required to produce zero current flow with freshwater is not appreciably different than the distance for seawater.

AFFF Test

A single test using 6% AFFF concentrate diluted with 94% seawater also was conducted using the 1-1/2 in., Type I 125 gpm nozzle with a source voltage of 440 volts. The conductivity of seawater was reduced only slightly, from a value of 58,000 to 56,300 microsiemens/cm, after mixing with the AFFF concentrate (3M Company's FC 206 CE brand). In view of this similarity in conductivity, it is not surprising that distances between nozzle and grid to obtain zero current flow, as shown in Table 12, were nearly the same for both agents.

Additional tests with both AFFF and seawater were conducted with a proposed new 3/4 in. nozzle and are discussed in the following section.

Proposed Type III Nozzle Test Results

The 3/4 in. Type III nozzle was subjected to the same test condition used for the previously tested 1-1/2 in. nozzles with synthetic seawater having a conductivity of 58,000 microsiemens/cm and fresh water from the CBD fire main with a conductivity of 370 microsiemens/cm, using all shipboard source voltages (120 dc, 120 ac, 440 ac and 4,160 ac). An additional test using 6% AFFF concentrate and 94% seawater with a conductivity of 56,300 microsiemens/cm was conducted with a voltage source of 440 V ac only. Electrical data are shown in Tables 21 through 24 for all stream patterns. The straight stream data also are shown graphically in Figs. 21 and 22. The data show that the distance to obtain zero current flow through 500 ohms resistance is less than 6 ft for seawater and less than 2 ft for fresh water with the straight stream pattern. Using fog patterns, a maximum distance of 1-1/2 ft was found with seawater and 1/2 ft with fresh water. Results using AFFF in seawater were similar to those for seawater alone with a

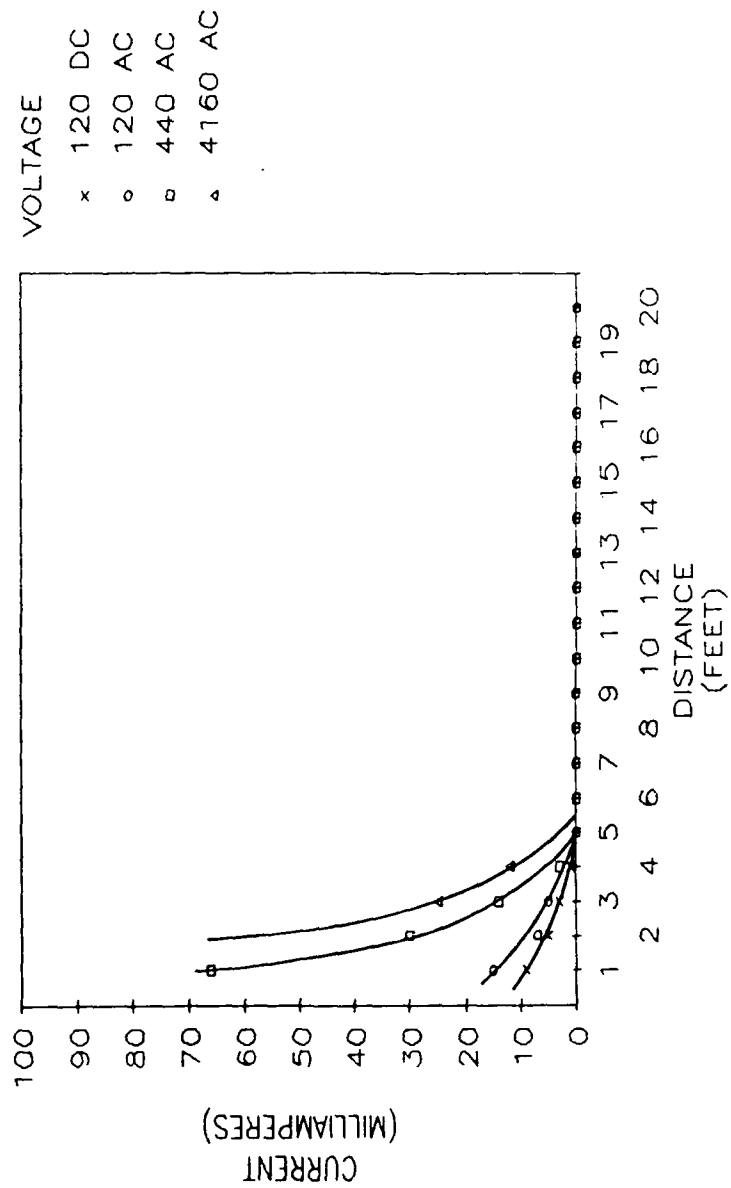


Fig. 21 - Straight stream nozzle currents: Proposed Type III
30 gpm nozzle, 30 psi nozzle pressure, seawater

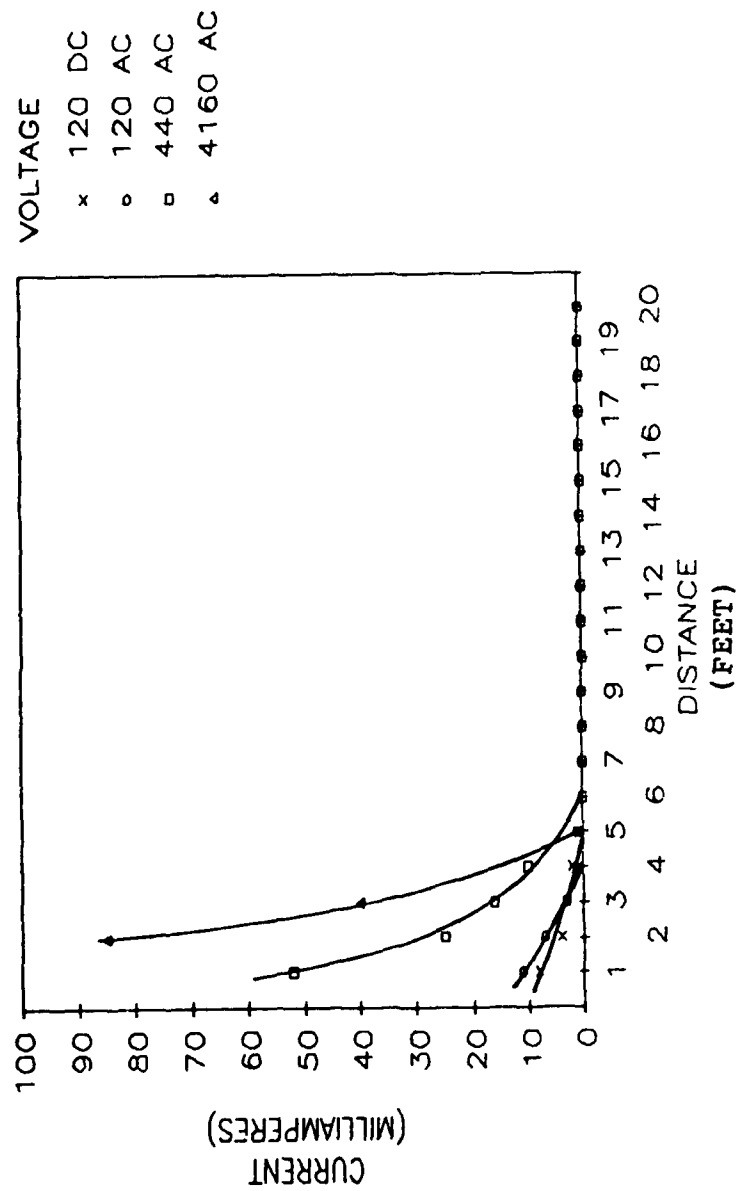


Fig. 22 - Straight stream nozzle currents: Proposed Type III
30 gpm nozzle, 100 psi nozzle pressure, seawater

distance of 6 ft for the straight stream pattern, 1 ft for the 30° fog pattern and 1/2 ft for the 90° fog pattern when using the 440 volt source.

Feecon Dual Agent (AFFF/PKP) Nozzle

The Feecon nozzle was evaluated with both seawater and fresh water using all shipboard voltage sources up to and including 4,160 volts.

Flow rates through the nozzle were found to vary from 84 to 100 gpm at 100 psi nozzle pressure and from 45 to 56 gpm at 30 psi pressure. A turbine type flow meter, used to monitor the flow rates, was calibrated prior to conducting the tests. The fluctuations in flow rate probably resulted from minor pressure variations which occurred while the electrical tests were conducted.

The distance of the seawater hose stream from the energized grid to the nozzle at the point of zero current flow ranged from 1 ft with most fog patterns at all source voltages, to 17 ft with the straight stream patterns at 4,160 volts. Using fresh water having an electrical conductivity of 370 microsiemens/cm, the equivalent distances to obtain zero current were considerably shorter for the straight stream and 30° fog pattern and approximately the same for the 90° fog patterns. Results using the Feecon nozzle under all test conditions are shown in Tables 25 through 28. Graphs plotted from the straight streams data are shown in Figs. 23 and 24.

Portable AFFF Extinguishers

The portable AFFF extinguisher was also subjected to hose stream conductivity tests using the same test apparatus previously described. The extinguisher was mounted on the rubber tired cart with its straight stream nozzle directed toward the target grid. The grid was energized with a 440 volt source. Fresh water having conductivity of 370 microsiemens/cm, a premixed 10% AFFF solution with fresh water with a conductivity of 1,300 microsiemens/cm, and a seawater premix with 56,500 microsiemens/cm conductivity were evaluated by adjusting the cart position to obtain zero current flow between a copper wire conductor attached to the plastic nozzle tip and ground. Results, as shown in Table 29, indicate that no current will flow at a distance of 3 in. with fresh water, 1 ft with 10% AFFF-fresh water premix and 3-1/2 ft with 10% AFFF-seawater premix. Data from Table 29 are plotted for visual comparison in Fig. 25.

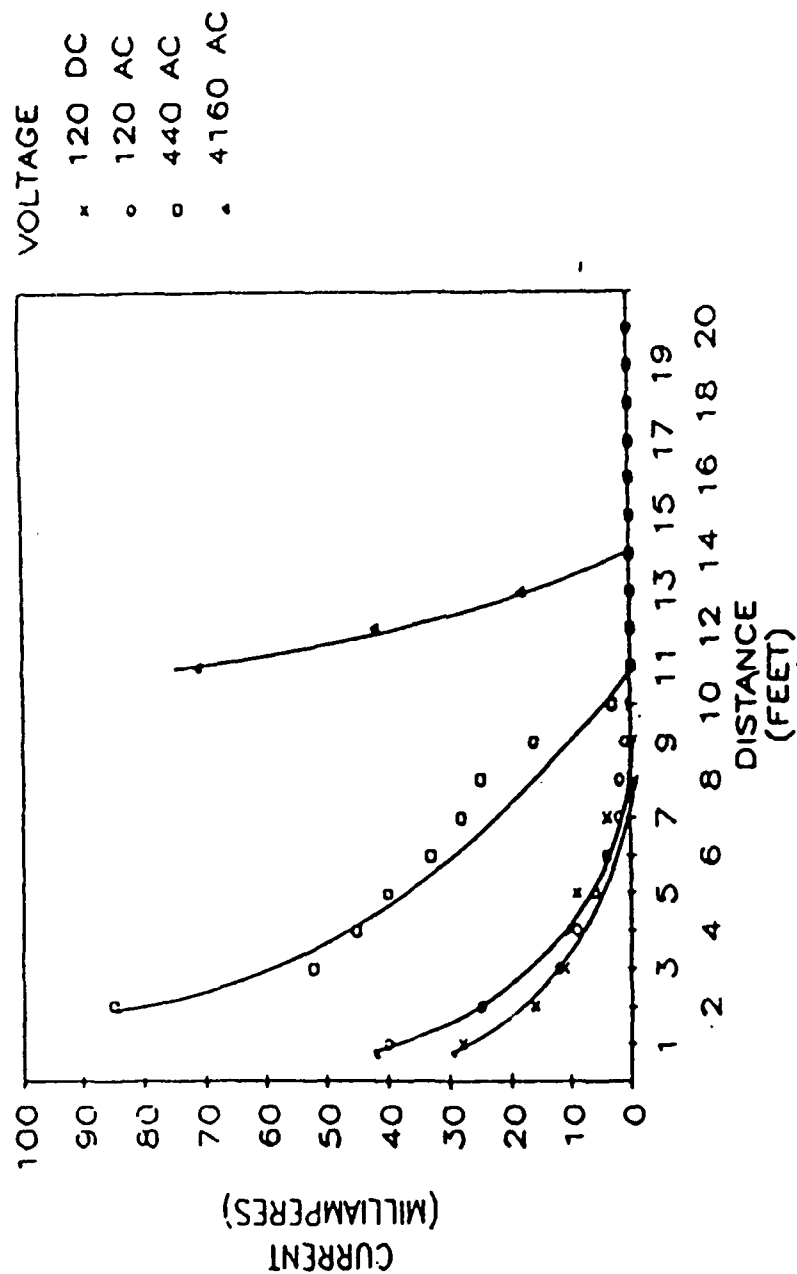


Fig. 23 - Straight stream nozzle currents: Feecon dual agent nozzle, 30 psi nozzle pressure, seawater

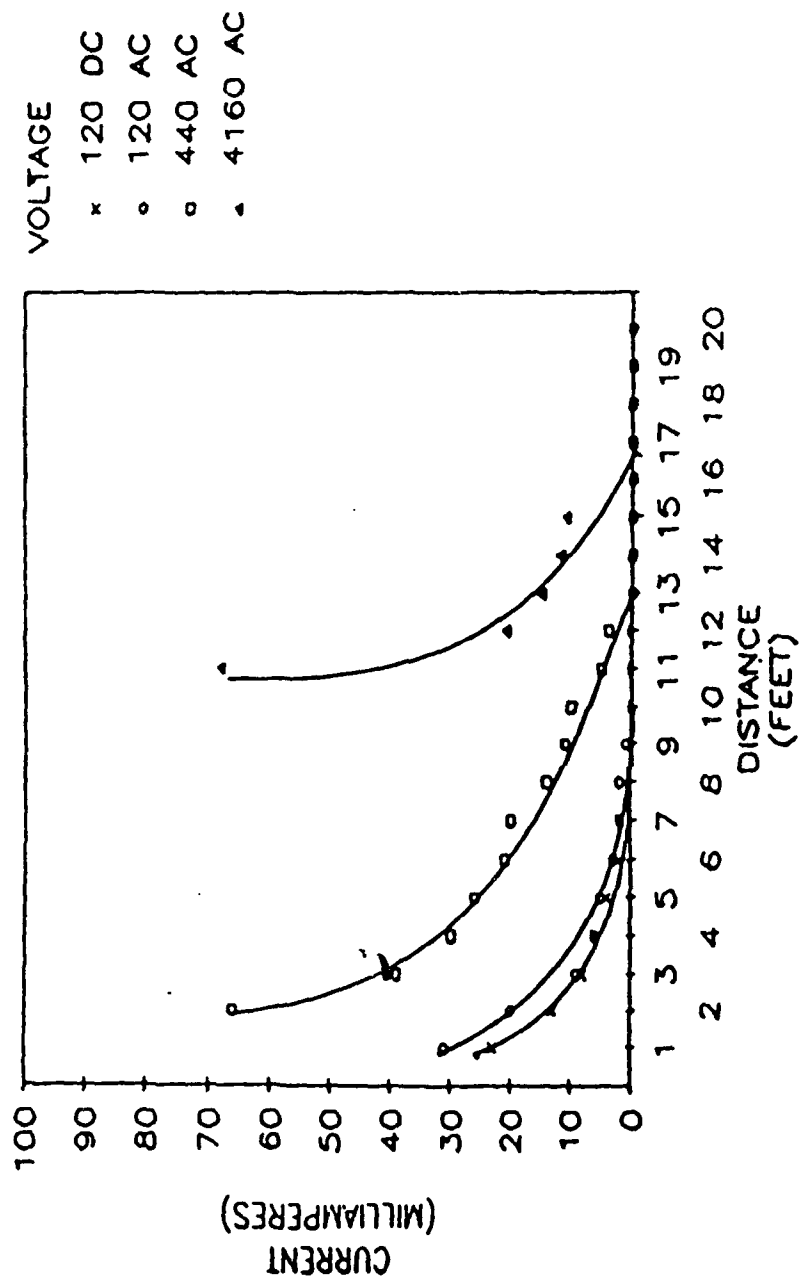


Fig. 24 - Straight stream nozzle currents: Feecon dual agent nozzle, 100 psi nozzle pressure, seawater

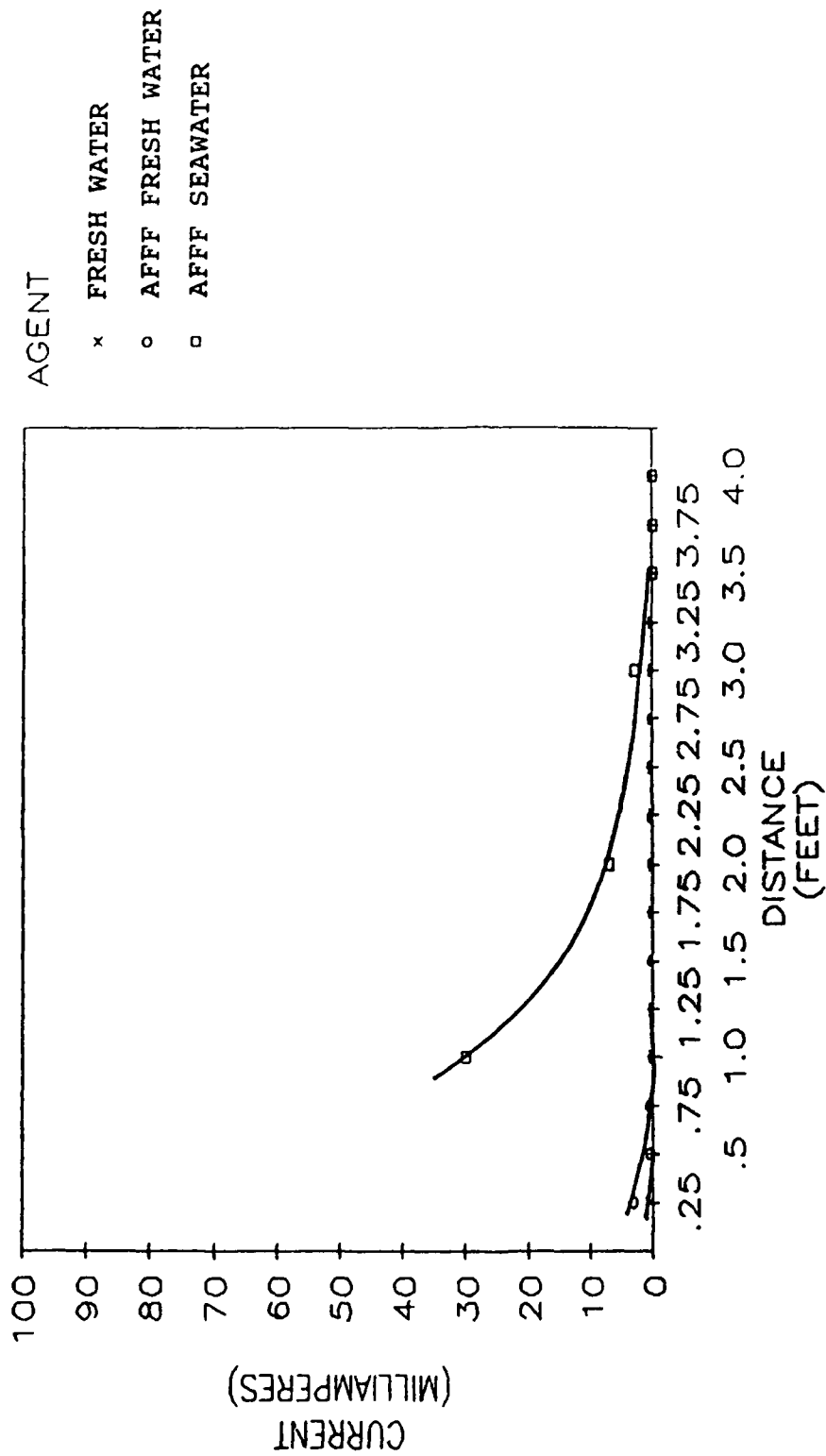


Fig. 25 - Straight stream nozzle currents: Portable AFFF extinguisher, 440 volt ac source

Current Flow in Test Set-Up

It is recognized that the entire current from the energized target did not pass through the 500 ohm test resistor representing a man. Both the current through the resistor and the current through the first section of the firehose depend upon the conductivity of the water used in the experiment. For the simulated seawater (conductivity of 58,000 microsiemens/cm), 88% of the current was calculated to flow through the 500 ohm resistor, and the remaining 12% would have flowed to ground at the next hose coupling. Fresh water from the CBD fire main had a conductivity of 370 microsiemens/cm resulting in a flow of 99.9% of the total current through the 500 ohm resistor.

Safety Considerations

The results of this study demonstrate that seawater can be used safely to extinguish fires involving electrically energized equipment. However, practical application of the data must be tempered with an understanding that shipboard fire fighting is often performed under conditions of limited visibility and high stress. Under these conditions, if, for example, preset fog patterns with the Type I and II nozzles are accidentally altered during fire fighting, safety may be seriously compromised. A fog pattern set at 30' can easily be inadvertently altered to a straight stream resulting in a diminished margin of safety. For instance, if the Type I MIL-N-24408 nozzle at 100 psi is altered from 30' fog to straight stream, the distance to zero current flow increases from less than 1 ft to 10-1/2 ft for either 120 dc or 120 ac source voltages (see Table 20). Consequently, great care must be exercised when using these nozzles to fight electrical fires.

CONCLUSIONS AND RECOMMENDATIONS

Seawater can be used safely to extinguish fires involving energized electrical equipment. However, the closest distance at which a fire fighter can safely approach such fires will depend upon the type of nozzle, the nozzle pattern and the voltage on the electrical equipment. For the nozzles tested, the furthest distances from the energized

target grid at which no current flowed from the nozzle to ground using seawater were as follows:

<u>Nozzle</u>	<u>Pattern</u>	<u>Maximum Observed Distance for Zero Current Flow, Feet</u>	<u>Voltage on Target Grid, Volts</u>
Navy All Purpose	Straight Stream	10*	2430
	Fog	0.5	4160
Type I	Straight Stream	22*	2430
	Fog	2*	2430
Type II	Straight Stream	17	4160
	Fog	3	4160
Type III (30 gpm)	Straight Stream	5.5**	440
	Fog	2	4160
Feecon	Straight Stream	17	4160
	Fog	2.5	4160

* Since the distance for 4160 volts was slightly lower, this value may be somewhat in error.

** The distance for 4160 volts was 4 feet.

In a typical shipboard fire fighting situation one can never be certain of the maximum voltage on equipment in a given compartment, the distance between the fire fighter and the equipment or even what type of nozzle might be available. Applying a safety factor to the distances above, it can readily be seen that there are few shipboard fire fighting situations where a straight stream pattern can be employed. Therefore, the use of straight stream patterns for this purpose is not recommended. However, fog patterns from any of the nozzles tested can be used effectively for fighting fires involving electrical equipment at voltages up to 4160 volts. It is recommended that a distance of at least 4 ft be maintained between the nozzle and electrical equipment with the nozzle set only on the fog pattern.

Portable AFFF extinguishers, containing 10% AFFF in seawater, produce no current flow to ground at a distance of 3-1/2 ft from a target grid charged to 440 volts. When fresh water is used to prepare the AFFF solution, the distance for zero current flow is only one foot. Therefore, these extinguishers may have some application for fighting

electrical fires on submarines, particularly if the AFFF solution is prepared with fresh water.

Finally, although test results indicate that the distance required to produce zero current flow is essentially the same for both fresh water and seawater, regardless of the nozzle type, there is a very significant difference between these fluids in the distances where electrocution and other dangerous physiological effects occur. Therefore, where available, fresh water should be used for fire fighting instead of seawater to further reduce the potential for electrical shock.

**Table 1 - Probable Effects of Electrical Shock
(External Contact) [Ref. 4]**

<u>AC (60 Hz) *</u>	<u>DC*</u>	<u>Effects</u>
0 - 1 mA	0 - 4 mA	Perception
1 - 4 mA	4 - 15 mA	Surprise
4 - 21 mA	15 - 80 mA	Reflex Action (freezing starts)
21 - 40 mA	8 - 160 mA	Muscular Inhibition
40 - 100 mA	160 - 300 mA	Respiratory Block
Over 100 mA	Over 300 mA	Fibrillation (usually fatal)

*For adult male; values for adult females are approximately 65% of these values.

Table 2 - Nozzle Flow Rate Data

TYPE	PATTERN	PRESSURE (psi)	FLOW RATE (gpm)
Navy All Purpose	SS	30	52.4
	FOG	30	28.6
	SS	100	98.0
	FOG	100	53.0
	SS	30	61.8
	FOG	30	61.3
MIL-N-24408 TYPE I (125 GPM) 1-1/2" HOSE	90° FOG	30	61.6
	SS	100	114.3
	30° FOG	100	114.9
	90° FOG	100	115.2
	SS	30	50.5
	30° FOG	30	50.6
MIL-N-24408 TYPE II (95 GPM) 1-1/2" HOSE	90° FOG	30	50.9
	SS	100	95.4
	30° FOG	100	95.6
	90° FOG	100	95.8
	SS	30	12.2
	30° FOG	30	12.3
MIL-N-24408 PROPOSED TYPE III (30 GPM)	90° FOG	30	12.3
	SS	100	23.8
	30° FOG	100	23.8
	90° FOG	100	23.7
	SS	30	46.1
	30° FOG	30	46.0
FEECON DUAL AGENT (COMMERCIAL VERSION) 95 GPM 1-1/2" HOSE	90° FOG	30	55.0
	SS	100	87.6
	30° FOG	100	87.1
	90° FOG	100	94.6

**Table 3 - Nozzle Current and Voltage versus Distance:
120 Volt dc Source, Navy All Purpose Nozzle**

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	110	105	105	88	350	250	SS
SW	1.5	95	85	5	38	9	65	SS
SW	2.5	75	60	3	20	4	30	SS
SW	3.5	55	35	2	10	3	15	SS
SW	4.5	45	20	13	5	20	7	SS
SW	5.0	35	15	10	2	15	4	SS
SW	5.5	30	15	8	1.5	11	3	SS
SW	6.5	25	5	5	0	7	3	SS
SW	7.0	-	-	1.5	-	3	-	SS
SW	7.5	8	-	1	-	2	-	SS
SW	8.0	0	0	0	-	0	-	SS
SW	0.5	0	0	0	0	0	-	FOG

*AGENT: SW = Seawater

Table 4 - Nozzle Current and Voltage versus Distance:
120 Volt dc Source, Type I 125 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	70	50	53	44	163	144	SS
SW	1.5	30	30	28	27	76	76	SS
SW	2.5	25	25	18	18	47	46	SS
SW	3.5	20	20	14	13	32	31	SS
SW	4.5	22	22	12	12	23	22	SS
SW	5.5	12	10	9	8	18	17	SS
SW	6.5	10	10	6	6	14	11	SS
SW	7.5	8	6	5	4	10	9	SS
SW	8.5	6	5	3	2	5	5	SS
SW	9.5	-	-	1	2	2	3	SS
SW	0.5	0	0	0	0	0	1	SS
SW	1.0	0	0	-	0	-	0	SS
SW	0.5	35	25	28	17	70	40	30° FOG
SW	1.0	0	0	1	0	2	1	30° FOG
SW	1.5	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

Table 5 - Nozzle Current and Voltage versus Distance:
120 Volt dc Source, Type II 95 gpm Nozzle
(Trigger Operated)

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	16	11	24	18	98	79	SS
SW	1.0	14	11	21	16	79	70	SS
SW	2.0	10	9	14	13	53	47	SS
SW	3.0	8	7	11	10	38	34	SS
SW	4.0	7	6	10	9	30	20	SS
SW	5.0	6	6	8	8	24	21	SS
SW	6.0	6	5	7	7	19	18	SS
SW	7.0	5	5	7	6	17	16	SS
SW	8.0	5	5	5	5	13	14	SS
SW	9.0	4	4	5	5	11	12	SS
SW	10.0	3	4	4	4	10	11	SS
SW	11.0	2	3	2	4	5	9	SS
SW	12.0	1	3	1	4	3	8	SS
SW	13.0	1	3	1	4	3	8	SS
SW	14.0	0	2	0	3	0	7	SS
SW	15.0	0	2	0	3	0	6	SS
SW	16.0	0	2	0	2	0	4	SS
SW	17.0	0	0	0	0	0	0	SS
SW	0.5	3	8	17	5	37	20	30° FOG
SW	1.0	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

Table 6 - Nozzle Current and Voltage versus Distance:
120 Volt ac Source, Navy All Purpose Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	125	110	158	114	620	580	SS
SW	1.5	115	45	80	38	168	126	SS
SW	2.5	80	25	43	17	75	50	SS
SW	3.5	55	30	26	13	43	26	SS
SW	4.5	45	20	17	7	26	12	SS
SW	5.5	35	0	15	7	31	16	SS
SW	6.0	-	10	0	1.8	0	6	SS
SW	6.5	20	10	2	0	5	1.3	SS
SW	7.5	12	5	0	0	1	0	SS
SW	8.5	5	-	0	-	0	-	SS
SW	0.5	0	0	0	0	0	0	30° FOG

*AGENT: SW = Seawater

Table 7 - Nozzle Current and Voltage versus Distance:
120 Volt ac Source, Type I 125 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	90	75	88	75	313	277	SS
SW	1.5	45	45	37	36	120	114	SS
SW	2.5	30	28	23	21	68	64	SS
SW	3.5	40	38	22	21	43	40	SS
SW	4.5	35	30	16	14	32	27	SS
SW	5.5	30	28	12	10	21	20	SS
SW	6.5	20	16	9	7	17	14	SS
SW	7.5	12	10	4	3	11	9	SS
SW	8.5	10	5	4	2	9	6	SS
SW	9.5	10	5	0	1	3	3	SS
SW	10.5	5	5	0	0	1	1	SS
SW	11.0	0	0	0	0	0	0	SS
SW	0.5	60	25	46	15	115	42	30° FOG
SW	1.0	8	2	1	0	5	1	30° FOG
SW	1.5	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

**Table 8 - Nozzle Current and Voltage versus Distance:
120 Volt ac Source, Type II 95 gpm Nozzle
(Trigger Operated)**

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	50	41	66	51	315	234	SS
SW	1.0	39	33	47	37	206	164	SS
SW	2.0	30	25	31	24	120	95	SS
SW	3.0	23	21	20	17	76	65	SS
SW	4.0	19	17	16	15	56	49	SS
SW	5.0	15	13	10	9	39	36	SS
SW	6.0	11	10	7	6	30	28	SS
SW	7.0	9	9	5	5	24	23	SS
SW	8.0	8	8	3	4	17	18	SS
SW	9.0	7	7	3	2	11	13	SS
SW	10.0	7	8	1	7	9	12	SS
SW	11.0	5	6	2	4	8	11	SS
SW	12.0	2	5	1	2	3	8	SS
SW	13.0	1	5	0	2	2	7	SS
SW	14.0	0	4	0	2	0	9	SS
SW	15.0	0	3	0	1	0	4	SS
SW	16.0	0	2	0	1	0	2	SS
SW	17.0	0	0	0	0	0	0	SS
SW	0.5	23	7	20	3	85	18	30° FOG
SW	1.0	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

Table 9 - Nozzle Current and Voltage versus Distance:
220 Volt ac Source, Navy All Purpose Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 ps	100 psi	
SW	0.5	130	125	235	195	760	610	SS
SW	1.5	100	70	78	56	190	150	SS
SW	2.5	95	80	49	40	86	66	SS
SW	3.5	55	40	26	20	50	36	SS
SW	4.5	45	30	17	11	29	19	SS
SW	5.5	30	18	8	4	16	10	SS
SW	6.5	25	15	2	1	6	2	SS
SW	7.0	15	10	1	0	3	0	SS
SW	7.5	-	10	0	-	0	-	SS
SW	0.5	0	0	0	0	0	0	FOG

*AGENT: SW = Seawater

Table 10 - Nozzle Current and Voltage versus Distance:
220 Volt ac Source, Type I 125 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	125	125	225	205	740	630	SS
SW	1.5	125	125	125	116	320	290	SS
SW	2.5	125	125	102	92	200	175	SS
SW	3.5	120	10	78	66	147	120	SS
SW	4.5	115	100	68	56	119	92	SS
SW	5.5	115	90	60	43	97	69	SS
SW	6.5	105	85	50	39	80	58	SS
SW	7.5	85	65	41	30	66	47	SS
SW	8.5	60	50	33	25	59	41	SS
SW	9.5	65	50	29	23	44	37	SS
SW	10.5	55	45	26	20	38	30	SS
SW	11.5	55	45	23	17	38	27	SS
SW	12.5	45	40	18	15	27	23	SS
SW	13.5	35	20	11	10	20	19	SS
SW	14.5	25	25	6	9	16	16	SS
SW	15.5	30	22	5	7	9	12	SS
SW	16.5	15	18	3	6	5	10	SS
SW	17.0	10	-	0	-	0	-	SS
SW	17.5	0	20	0	3	0	7	SS
SW	18.5	0	20	-	3	-	7	SS
SW	18.5	0	18	-	3	-	7	SS
SW	19.0	0	10	-	0	-	1	SS
SW	19.5	0	10	-	0	-	0	SS
SW	0.5	125	85	135	50	285	100	30° FOG
SW	1.0	5	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

Table 11 - Nozzle Current and Voltage versus Distance:
440 Volts ac Source, Navy All Purpose Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	125	125	OL**	560	OL**	1900	SS
SW	1.0	140	140	360	260	900	720	SS
SW	1.5	150	130	270	225	550	425	SS
SW	2.5	125	130	156	130	280	215	SS
SW	3.5	125-150	140-160	98	70	155	110	SS
SW	4.5	140-160	110-130	58	39	90	60	SS
SW	5.5	120-140	80-100	25	20	44	30	SS
SW	6.5	90-110	50-70	19	8	30	11	SS
SW	7.5	60-100	25-50	4	15	10	3	SS
SW	8.0	0-40	0-20	0	0	2	0	SS
SW	8.5	0-30	0-20	0	0	0	0	SS
SW	0.5	0	0	0	0	0	0	FOG

*AGENT: SW = Seawater

**OL: Overload (milliammeter overloads with current greater than 2,000 mA)

**Table 12 - Nozzle Current and Voltage versus Distance:
440 Volt ac Source, Type I 125 gpm Nozzle**

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	125	125	413	333	1260	1050	SS
SW	1.5	65	60	126	131	420	405	SS
SW	2.5	65	65	66	67	245	230	SS
SW	3.5	55	50	49	46	159	150	SS
SW	4.5	40	35	36	33	115	105	SS
SW	5.5	35	35	29	29	86	76	SS
SW	6.5	35	30	25	25	55	56	SS
SW	7.5	35	25	20	18	49	42	SS
SW	8.5	20	18	14	10	35	29	SS
SW	9.5	5	12	3	6	6	21	SS
SW	10.5	10	10	3	3	8	9	SS
SW	11.5	0-10	5-10	0	1	0	1	SS
SW	12.5	0	0-10	0	0	0	1	SS
SW	13.5	0	0	-	0	-	0	SS
SW	0.5	135	80	182	64	430	170	30° FOG
SW	1.0	15	10	7	2	19	8	30° FOG
SW	1.5	0	0	0	0	0	0	30° FOG
SW	0.5	5	0	0	0	0	0	90° FOG
AFFF	1.0	22	19	21	14	543	485	SS
AFFF	2.0	13	11	7	5	277	261	SS
AFFF	3.0	16	15	11	3	227	152	SS
AFFF	4.0	11	8	5	4	161	153	SS
AFFF	5.0	15	9	10	4	101	112	SS
AFFF	6.0	4	3	27	22	82	85	SS
AFFF	7.0	4	2	1	0	57	34	SS
AFFF	8.0	3	4	1	1	61	52	SS
AFFF	9.0	1	1	3	1	31	52	SS
AFFF	10.0	2	3	16	17	75	80	SS
AFFF	11.0	2	1	6	3	63	65	SS
AFFF	12.0	0	0	0	0	0	0	SS
AFFF	0.5	8	3	3	0	252	71	30° FOG
AFFF	1.0	0	0	0	0	0	0	30° FOG
AFFF	0.5	0	0	0	0	0	0	90° FOG
AFFF	1.0	0	0	0	0	0	0	90° FOG

*AGENT: SW = Seawater

AFFF = 6% AFFF Concentrate + 94% Seawater

**Table 13 - Nozzle Current and Voltage versus Distance:
440 Volt Source, Type II 95 gpm Nozzle
(Trigger Operated)**

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	197	-	-	206	-	647	SS
SW	1.0	178	160	214	182	573	483	SS
SW	2.0	143	125	132	115	356	301	SS
SW	3.0	108	98	108	88	233	205	SS
SW	4.0	90	84	80	59	176	146	SS
SW	5.0	70	64	60	43	130	112	SS
SW	6.0	58	54	19	34	72	90	SS
SW	7.0	51	44		37	15	84	SS
SW	8.0	47	46	0	35	22	31	SS
SW	9.0	38	42	15	29	38	59	SS
SW	10.0	20	50	12		35		SS
SW	11.0	4	27	0	11	33	36	SS
SW	12.0	4	23	0	3	3	27	SS
SW	13.0	2	22	0	1	5	20	SS
SW	14.0	0	19	0	0	0	16	SS
SW	15.0	2	20	0	3	0	5	SS
SW	16.0	1	5	0	1	0	7	SS
SW	17.0	2	3	0	0	0	2	SS
SW	18.0	2	3	0	0	0	2	SS
SW	19.0	1	5	0	0	0	0	SS
SW	0.5	12	3	3	0	13	2	30° FOG
SW	1.0	1	1	0	0	0	0	30° FOG
SW	2.0	0	0	0	0	0	0	30° FOG
SW	0.5	2	2	0	0	0	0	90° FOG

*AGENT: SW = Seawater

Table 14 - Nozzle Current and Voltage versus Distance:
2430 Volt Source, Navy All Purpose Nozzle

Agent*	Dis tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)					Hose Stream Pattern
		30 psi	100 psi	0 Ohms					
				30 psi	100 psi	30 psi	100 psi	100 psi	
SW	4.0	475-500	390-425	OL**	OL**	OL**	OL**	OL**	SS
SW	5.0	220-300	120-230	120-175	90-100	125-165	100-140	100-140	SS
SW	6.0	20-100	100-150	50-100	50-75	70-130	60-100	60-100	SS
SW	7.0	20-60	20-40	20-55	20-30	35-60	20-40	20-40	SS
SW	8.0	3-6	3-11	0	1-10	1-12	3-10	3-10	SS
SW	10.0	0	0	0	0	0	0	0	SS
SW	12.0	0	0	0	0	0	0	0	SS
SW	0.5	0	0	0	0	0	0	0	FOG
SW	1.0	0	0	0	0	0	0	0	FOG

* SW = Seawater

** OL = Overload - (milliampmeter overloads with currents greater than
2000 milliamps)

Table 15 - Nozzle Current and Voltage versus Distance:
2430 Volt ac Source, Type I 125 gpm Nozzle

Agent*	Dis tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)					Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms			
				30 psi	100 psi	30 psi	100 psi	30 psi	
SW	12.0	100-300	250-300	150-250	225	200-42	290	SS	
SW	13.0	80-120	250-300	0-40	90	0-60	150	SS	
SW	14.0	36-116	150-250	10-50	10-40	100-130	60-100	SS	
SW	15.0	29-141	200-260	10-60	70-105	24-88	90-120	SS	
SW	16.0	0-9	150-220	1-25	60-80	10-54	65-110	SS	
SW	17.0	0	40-60	0	10-40	0	20-50	SS	
SW	18.0	0	34-60	0	10-20	0	20-40	SS	
SW	19.0	0	11-40	-	6-25	-	10-30	SS	
SW	20.0	-	10-30	-	15-35	-	15-30	SS	
SW	21.0	-	10-30	-	10-20	-	10-20	SS	
SW	22.0	-	0	-	0	-	0	SS	
SW	0.5	1200	470	OL**	580	OL**	1500	30° FOG	
SW	1.0	28	2	40	2	25	6	30° FOG	
SW	2.0	0	0	0	0	0	0	30° FOG	
SW	0.5	0	0	0	0	0	0	90° FOG	

* SW = Seawater

** OL = Overload - (milliampmeter overloads with currents greater than
2,000 milliamps)

Table 16 - Nozzle Current and Voltage versus Distance:
4160 Volt Source, Navy All Purpose Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage		Nozzle to Ground Current (milliamperes)						Hose Stream Pattern
		(volts)		500 Ohms		0 Ohms				
		30 psi	100 psi	30 psi	100 psi	30 psi	100 psi	30 psi	100 psi	
SW	4.0	240	200	236	200	485	450			SS
SW	4.5	300	250	335	250	750	543			SS
SW	5.0	130	100	183	114	300	253			SS
SW	6.0	90	70	70	73	184	140			SS
SW	7.0	50	30	43	36	80	67			SS
SW	8.0	0	20	5	7	9	19			SS
SW	9.0	0	10	0	0	0	4			SS
SW	10.0	0	10	0	0	0	0			SS
SW	0.5	0	10	0	0	1	0			FOG
SW	1.0	0	10	0	0	0	0			FOG

* SW = Seawater

Table 17 - Nozzle Current and Voltage versus Distance:
4160 Volt Source, Type I 125 gpm Nozzle

Agent*	Dis tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	30 psi	100 psi	500 Ohms	0 Ohms	
SW	9.0	-	275	-	260	490	SS	SS
SW	9.5	-	275	-	247	410	SS	SS
SW	10.0	300	250	380	212	348	SS	SS
SW	11.0	240	200	230	190	352	SS	SS
SW	12.0	170	180	154	175	318	SS	SS
SW	13.0	80	150	68	180	245	SS	SS
SW	14.0	0	120	0	68	135	SS	SS
SW	15.0	0	100	0	72	153	SS	SS
SW	16.0	0	65	0	47	80	SS	SS
SW	17.0	0	50	0	40	52	SS	SS
SW	18.0	0	40	0	22	45	SS	SS
SW	19.0	0	3	0	0	0	SS	SS
SW	0.5	409-412	197-200	OL**	OL**	OL**	30° FOG	30° FOG
SW	0.75	162-175	39-OL**	185-204	63	780-841	30° FOG	30° FOG
SW	1.0	42-51	5-8	65-71	10	170-185	30° FOG	30° FOG
SW	1.5	0*	0*	0*	0*	0*	30° FOG	30° FOG
SW	0.5	1	0*	2-4	0*	8-10	90° FOG	90° FOG
SW	0.75	0*	0*	0*	1	0*	90° FOG	90° FOG
SW	1.0	0*	0*	0*	0*	0*	90° FOG	90° FOG

* SW = Seawater

** OL = Overload - (milliammeter overloads at >2000 mA, voltmeter overloads at >4000 watts)

Table 18 - Nozzle Current and Voltage versus Distance:
4160 Volt Source, Type II 95 gpm Nozzle
(Trigger Operated)

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	9.0	250	280	270	290	590	66	SS
SW	10.0	300	250	220	250	490	560	SS
SW	11.0	150	200	140	210	340	490	SS
SW	12.0	100	175	115	180	190	430	SS
SW	13.0	25	150	60	160	140	350	SS
SW	14.0	10	100	101	30	40	280	SS
SW	15.0	2	50	1	25	1	100	SS
SW	16.0	1	0	0	1	0	1	SS
SW	17.0	0	0	0	0	0	0	SS
SW	0.5	400	20	580	30	1400	800	30° FOG
SW	1.0	100	10	100	12	300	15	30° FOG
SW	2.0	1	1	1	1	1	1	30° FOG
SW	3.0	1	0	0	0	0	0	30° FOG
SW	0.5	2	6	0	0	15	15	90° FOG
SW	1.0	1	1	0	0	0	0	90° FOG

*AGENT: SW = Seawater

**Table 19 - Nozzle Current and Voltage versus Distance:
Fresh Water, 4160 Volt Source, Type I 125 gpm Nozzle,
Straight Stream and Fog**

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
FW	0.25	52	36	51	32	95	59	SS
FW	0.50	36	28	32	24	58	49	SS
FW	1.0	20	17	18	15	35	30	SS
FW	2.0	10	9	9	8	19	15	SS
FW	3.0	8	6	7	5	13	10	SS
FW	4.0	6	4	5	4	10	7	SS
FW	5.0	6	4	5	3	8	6	SS
FW	6.0	5	3	4	3	6	4	SS
FW	7.0	4	2	3	2	5	4	SS
FW	8.0	2	2	2	1	4	3	SS
FW	9.0	2	1	2	1	3	2	SS
FW	10.0	2	1	2	1	3	2	SS
FW	11.0	1	1	1	1	2	1	SS
FW	12.0	1	0	1	1	1	1	SS
FW	13.0	1	1	1	1	1	1	SS
FW	14.0	0	0	1	1	1	1	SS
FW	15.0	0	0	0	1	1	1	SS
FW	16.0	0	0	0	0	0	1	SS
FW	17.0	0	0	0	0	0	0	SS
FW	0.25	30	8	26	6	48	11	30° FOG
FW	0.5	0	0	0	0	0	0	30° FOG
FW	0.25	1	0	1	0	1	0	90° FOG
FW	0.5	0	0	0	0	0	0	90° FOG

*AGENT: FW = Fresh Water

Table 20 - Nozzle Distance (ft) to Detect Zero Current Through 500 ohm Resistor with Seawater

NOZZLE PRESSURE (psi)	SOURCE VOLTAGE	Distance From Nozzle to Target at Zero Current (ft)											
		MIL-N-24408 Type I (125 gpm)						MIL-N-24408 Type II (95 gpm)					
		Navy All Purpose		SS		FOG		SS		30° FOG		90° FOG	
		30	100	30	100	30	100	30	100	30	100	30	100
120 dc		8.0	6.5	0.5	0.5	10.5	10.5	1.5	1.0	0.5	0.5	14.0	17.0
								1.0	1.0	1.0	1.0	0.5	0.5
120 ac		7.5	6.5	0.5	0.5	9.5	10.5	1.5	1.0	0.5	0.5	13.0	17.0
								1.0	1.0	0.5	0.5	11.5*	14.5*
220 ac		7.5	7.0	0.5	0.5	17.0	19.0	1.0	1.0	0.5	0.5	1.5*	1.0*
								1.5	1.5	0.5	0.5	1.0	0.5
440 ac		8.0	8.0	0.5	0.5	11.5	12.5	1.5	1.5	0.5	0.5	11.0	14.0
								2.0	1.5	2.0	0.5	10.0*	13.0*
2430 ac		8.0	10.0	0.5	0.5	17.0	22.0	1.5	1.5	2.0	0.5	2.0*	2.0*
								1.5	1.5	1.0	1.0	1.0*	0.5*
4160 ac		9.0	9.0	0.5	0.5	14.0	19.0	1.5	1.5	1.0	1.0	3.0	3.0
								1.5	1.5	1.0	1.0	0.5	0.5

*Data are for a 125 gpm commercial nozzle.

Table 21 - Nozzle Current and Voltage versus Distance:
120 Volt dc Source, Proposed Type III 30 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	7	6	9	8	28	24	SS
SW	1.0	8	7	9	8	22	19	SS
SW	2.0	5	4	5	4	12	10	SS
SW	3.0	3	2	3	3	6	6	SS
SW	4.0	0	2	1	2	1	4	SS
SW	5.0	0	0	0	1	0	2	SS
SW	6.0	0	0	0	0	0	0	SS
SW	0.5	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	60° FOG
FW	0.5	0	0	2	2	0	0	SS
FW	1.0	0	0	0	0	0	0	SS
FW	0.5	0	0	0	0	0	0	30° FOG
FW	0.5	0	0	0	0	0	0	60° FOG

*AGENT: SW = Seawater
FW = Fresh Water

Table 22 - Nozzle Current and Voltage versus Distance:
120 Volt ac Source, Proposed Type III 30 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	23	18	21	16	56	41	SS
SW	1.0	18	15	15	11	38	32	SS
SW	2.0	10	21	7	7	19	15	SS
SW	3.0	14	5	5	3	8	7	SS
SW	4.0	1	2	0	0	0	1	SS
SW	5.0	0	0	0	0	0	0	SS
SW	0.5	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	60° FOG
FW	0.5	0	0	0	2	0	0	SS
FW	1.0	0	0	0	0	0	0	SS
FW	0.5	0	0	0	0	0	0	30° FOG
FW	0.5	0	0	0	0	0	0	60° FOG

* AGENT: SW = Seawater
FW = Fresh Water

Table 23 - Nozzle Current and Voltage versus Distance:
440 Volt ac Source, Proposed Type III 30 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	0.5	90	72	87	68	192	144	SS
SW	1.0	71	58	66	52	132	106	SS
SW	1.5	50	42	44	35	86	71	SS
SW	2.0	37	32	30	25	61	51	SS
SW	2.5	30	27	21	19	39	37	SS
SW	3.0	19	35	14	16	26	27	SS
SW	3.5	6	17	4	9	10	18	SS
SW	4.0	9	11	3	10	0	12	SS
SW	4.5	0	5	0	1	0	0	SS
SW	5.5	0	0	0	0	0	0	SS
SW	0.5	0	0	0	0	0	0	30° FOG
SW	0.5	0	0	0	0	0	0	60° FOG
FW	0.5	2	2	0	0	0	0	SS
FW	0.5	0	0	0	0	0	0	30° FOG
FW	0.5	0	0	0	0	0	0	60° FOG
AFFF	0.5	67	63	68	62	229	206	SS
AFFF	1.0	48	41	43	37	142	130	SS
AFFF	2.0	17	23	19	14	60	51	SS
AFFF	3.0	16	14	18	6	30	23	SS
AFFF	4.0	9	10	3	3	12	12	SS
AFFF	5.0	3	7	1	2	2	8	SS
AFFF	6.0	0	0	0	0	0	0	SS
AFFF	0.5	8	3	0	0	2	0	30° FOG
AFFF	1.0	0	0	0	0	0	0	30° FOG
AFFF	0.5	0	0	0	0	0	0	60° FOG

*AGENT: SW = Seawater
FW = Fresh Water
AFFF = 6% AFFF Concentrate/94% Seawater

Table 24 - Nozzle Current and Voltage versus Distance:
4160 Volt Source, Proposed Type III 30 gpm Nozzle

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	2.0	75	75	105	85	225	200	SS
SW	3.0	20	40	25	40	50	60	SS
SW	3.5	4	25	12	35	15	40	SS
SW	4.0	2	2	0	0	1	1	SS
SW	5.0	1	1	0	0	0	0	SS
SW	0.5	110	70	120	76	300	185	30° FOG
SW	1.0	100	10	20	18	40	40	30° FOG
SW	1.5	1	1	0	0	0	0	30° FOG
SW	0.5	40	25	39	31	117	75	60° FOG
SW	1.0	1	7	0	8	0	34	60° FOG
SW	1.5	1	1	0	0	0	0	60° FOG
FW	0.5	4	3	5	2	6	4	SS
FW	1.0	3	2	2	1	3	2	SS
FW	2.0	2	2	0	0	1	1	SS
FW	3.0	2	1	0	0	0	1	SS
FW	4.0	2	1	0	0	0	1	SS
FW	5.0	1	1	0	0	0	1	SS
FW	5.5	1	1	0	0	0	0	SS
FW	0.5	1	1	0	0	0	0	30° FOG
FW	1.0	1	1	0	0	0	0	30° FOG
FW	0.5	1	1	0	0	1	1	60° FOG
FW	1.0	1	1	0	0	0	0	60° FOG

*AGENT: SW = Seawater
FW = Fresh Water

Table 25 - Nozzle Current and Voltage versus Distance:
Feecon Dual Agent Nozzle, 120 Volt dc Source

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	1.0	19	15	28	23	118	118	SS
SW	2.0	11	9	16	13	64	53	SS
SW	3.0	8	6	11	8	43	32	SS
SW	4.0	6	5	9	6	28	19	SS
SW	5.0	4.5	3.5	10.5	4	18	12	SS
SW	6.0	2.5	1.5	4	2	11	6	SS
SW	7.0	3	1.5	4	2	12	6	SS
SW	8.0	1	0	0	0	0	1	SS
SW	9.0	0.5	0	2	0.5	5	2	SS
SW	10.0	0	0	0	0	0	0	SS
SW	11.0	2	0	2	0	6	0	SS
SW	12.0	0	0	0	0	0	0	SS
SW	0.5	13	7.5	20	11	103	54	30° FOG
SW	1.0	4.5	3.5	6	5	27	20	30° FOG
SW	1.5	2.5	2.5	3	3.5	15	14	30° FOG
SW	2.0	0	0.5	2	1	2	4	30° FOG
SW	2.5	0	0	0	0	0	0	30° FOG
SW	1.0	0	0	0	0	0	0	90° FOG
FW	0.5	0	0.2	0.5	0.2	1	0.7	SS
FW	1.0	0	0	0	0	0	0	SS
FW	1.5	0	0	0	0	0	0	SS
FW	0.5	0	0.1	0	0.1	0	0.3	30° FOG
FW	1.0	0	0	0	0	0	0	30° FOG
FW	0.5	0.1	0.1	0.2	0.2	0.5	0.5	60° FOG
FW	1.0	0	0	0	0	0	0	60° FOG

*AGENT - SW = Seawater
FW = Fresh Water

Table 26 - Nozzle Current and Voltage versus Distance:
Feecon Dual Agent Nozzle, 120 Volt ac Source

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	1.0	26	21	40	31	190	195	SS
SW	2.0	17	13	25	20	113	85	SS
SW	3.0	8	6	12	9	60	60	SS
SW	4.0	6	4	9	6	40	30	SS
SW	5.0	4.5	3	6	5	30	20	SS
SW	6.0	3	2	4	3	20	15	SS
SW	7.0	2	1.5	30	2	16	10	SS
SW	8.0	1.5	1.5	2	2	9	7	SS
SW	9.0	0.5	0.5	1	1	3	4	SS
SW	10.0	0.5	0.5	0	0	1	2	SS
SW	11.0	0	0	0	0	0	0	SS
SW	0.5	13	6	20	8	100	45	30° FOG
SW	1.0	0.5	1.5	0	2	1	9	30° FOG
SW	1.5	0	0	0	0	0	0	30° FOG
SW	0.5	1	0.5	1	0	5	0	60° FOG
SW	1.0	0	0	0	0	0	0	60° FOG
FW	0.5	0	0	0.6	0	1	0	SS
FW	1.0	0	0	0	0	0	0	SS
FW	0.5	0	0	0	0	0	0	30° FOG
FW	1.0	0	0	0	0	0	0	60° FOG

*AGENT - SW = Seawater
FW = Fresh Water

Table 27 - Nozzle Current and Voltage versus Distance:
Feecon Dual Agent Nozzle, 440 Volt ac Source

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	2.0	55	44	85	66	400	300	SS
SW	3.0	33	26	52	39	250	194	SS
SW	4.0	27	20	40	30	180	135	SS
SW	5.0	35	20	45	26	120	88	SS
SW	6.0	22	17	33	20	90	67	SS
SW	7.0	20	17	28	21	86	56	SS
SW	8.0	17	12	5	14	6	40	SS
SW	9.0	5	10	16	11	30	22	SS
SW	10.0	5	5	3	10	6	30	SS
SW	11.0	0	6	0	5	0	7	SS
SW	12.0	3	2	0	4	0	16	SS
SW	13.0	2	1	1	0	10	0	SS
SW	14.0	0	1	0	2	0	6	SS
SW	15.0	0	1.5	0	0	0	3	SS
SW	16.0	0	1.5	0	0	0	0	SS
SW	0.5	184	127	220	139	560	316	30° FOG
SW	1.0	25	25	30	30	70	75	30° FOG
SW	1.5	5	0	6	0	20	0	30° FOG
SW	2.0	0	0	0	0	0	0	30° FOG
SW	0.5	14	13	14	1.2	30	2.9	90° FOG
SW	1.0	0	0	0	0	0	0	90° FOG
FW	0.5	2	1	2	1	5	3	SS
FW	1.0	0.5	0.5	0.5	0.5	2.5	2	SS
FW	2.0	0.5	0	0.5	0	1.3	0	SS
FW	2.5	0	0	0	0	1	0	SS
FW	3.0	0	0	0	0	0	0	SS

*AGENT - SW = Seawater
FW = Fresh Water

Table 28 - Nozzle Current and Voltage versus Distance:
Feecon Dual Agent Nozzle, 4160 Volt ac Source

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)		Nozzle to Ground Current (milliamperes)				Hose Stream Pattern
		30 psi	100 psi	500 Ohms		0 Ohms		
				30 psi	100 psi	30 psi	100 psi	
SW	10.0	77	35	50	270	536	1200	SS
SW	11.0	54	49	71	68	518	202	SS
SW	12.0	19	35	18	15	25	108	SS
SW	13.0	24	35	42	21	70	199	SS
SW	14.0	1	14	0	5-10	4	18-40	SS
SW	15.0	0	12	0	11	0	22	SS
SW	16.0	0	16	0	15	0	30	SS
SW	17.0	0	1	0	0	0	0	SS
SW	0.5	230	122	375	875	1986	290-200	30° FOG
SW	1.0	37	22	5	1-3	43	7-9	30° FOG
SW	2.0	6	7	20	3	5	6	30° FOG
SW	2.5	0	0	0	0	0	0	30° FOG
SW	0.5	8	0	14	0	75	0	90° FOG
SW	1.0	0	0	0	0	0	2	90° FOG
SW	2.0	0	0	0	0	0	0	90° FOG
FW	0.5	6	4.5	9	7	33	36	SS
FW	1.0	4	3	6	4	24	18	SS
FW	2.0	2	1.5	3	2	14	10	SS
FW	3.0	1.5	1	2	2	9	7	SS
FW	4.0	1	0.5	2	1	7	5	SS
FW	5.0	1	0.5	2	1	5	3	SS
FW	6.0	0.5	0.5	1	1	4	2	SS
FW	7.0	0.5	0.5	1	1	3	2	SS
FW	8.0	0.5	0.5	1	1	2	2	SS
FW	9.0	0.5	0.5	1	0	2	2	SS
FW	10.0	0.5	0.5	1	0	2	1	SS
FW	11.0	0	0	0	0	1	0	SS
FW	12.0	0	0	0	0	0	0	SS
FW	0.5	1.5	0	2	0	10	2	30° FOG
FW	1.0	0	0	0	0	0	0	30° FOG
FW	0.5	0	0	0	0	0	0	60° FOG

AGENT* - SW = Seawater
FW = Fresh Water

Table 29 - Nozzle Current and Voltage versus Distance:
Portable AFFF Extinguisher, 440 Volt ac Source

Agent*	Dis- tance (ft)	Nozzle to Ground Voltage (volts)	Nozzle to Ground Current (milliamperes)		Hose Stream Pattern
			500 Ohms	0 Ohms	
FW	0.25	0.5	0.5	2.0	SS
FW	0.5	0	0	0	SS
AFFF/FW	0.25	3.0	3.2	7.0	SS
AFFF/FW	0.5	0.5	0.6	2.0	SS
AFFF/FW	0.75	0.4	0.5	1.3	SS
AFFF/FW	1.0	0	0	0	SS
AFFF/SW	1.0	20	30	75	SS
AFFF/SW	2.0	7	7	15	SS
AFFF/SW	3.0	5	2.9	11	SS
AFFF/SW	3.5	0	0	0	SS
AFFF/SW	4.0	0	0	0	SS

*AGENT - FW = Fresh Water

AFFF/FW = 10% AFFF/90% Fresh Water

AFFF/SW = 10% AFFF/90% Seawater

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APPENDIX A LITERATURE SURVEY

This literature survey was conducted to identify additional information on shock hazard to fire fighters when combating fires involving energized electrical equipment. The survey included publications of the following organizations:

- a. National Board of Fire Underwriters [5]*
- b. Factory Mutual [6]
- c. National Fire Protection Association [7,9]
- d. U.S. Navy [8,10]
- e. Purdue University [12,13]
- f. Underwriters Laboratories Inc. [14,15]
- g. Fire Journal [16,17]
- h. Nuclear Regulatory Commission [18]
- i. Naval Research Laboratory [19]

The National Board of Fire Underwriters (NBFU) [5] identifies the parameters which control the amount of current reaching the nozzle of fire fighting water streams (fresh water) as being:

- a. the voltage of the wire or device;
- b. the distance from the nozzle to the electrically charged line or device;
- c. the purity of the water in the stream; and
- d. whether the stream is solid or broken.

It is stated that, for wiring carrying up to 120 volts, any type of nozzle can be used within a few inches of the charged wire without endangering firemen. For a cable carrying 550 volts, the distance at which a straight stream nozzle can be held without discomfort is 3 to 4 ft. Minimum safe distances for the use of both solid stream and spray

* Numbers in brackets identify references listed after the main body of the report.

nozzles are shown in tabular form in the Special Interest Bulletin for equipment operating up to 33,000 volts for straight stream nozzles and 345,000 volts for spray nozzles. Minimum safe distances of 18 and 27 ft are prescribed for 1-1/8 in. and 1-1/2 in. straight stream nozzles, respectively, to combat fires on equipment operating at 5,500 volts. The minimum safe distance for combating fires with spray nozzles operating up to 15,000 volts is shown to be only 6 in. However, a warning is appended to each table indicating that the information applies only to fresh water and not seawater. It is emphasized that if it becomes necessary to use water known to have high conductivity, then a spray stream should be employed. Our findings in this study show that although spray (fog pattern) is preferred, that straight streams would not be hazardous under guidelines specified in this report.

Factory Mutual information [6] indicates that existing shipboard non-conducting extinguishing agents (CO₂, dry chemical and Halon) can be used safely on equipment operating at 100,000 volts, but emphasizes that no part of the extinguisher is to be brought within sparking distance of a high voltage conductor. A clearance of 1 ft is considered adequate but 2 to 3 ft is recommended to provide an adequate safety margin. Foam streams are stated to have high electrical resistance because of their discontinuity. Test results presented show that foam streams can be used within 5 in. of circuits operating at 550 volts. However, the use of foam on electrical fires is not recommended because of possible short circuits caused by masses of foam adhering to electrical equipment. It is assumed that the Factory Mutual remarks on the use of foam apply to either mechanical foam or protein foam no longer used on Navy ships. However, the use of AFFF on energized electrical fires should be explored and some data with this agent are included in this report. The use of water spray is recommended in the event that the fire cannot be controlled with available, non-conducting agents. It is stated that no appreciable current is conducted by streams of water (fresh or salt) from spray nozzles directed on live high voltage conductors up to 250,000 volts if the nozzles are 6 ft or more from the conductors: at voltages below 33,000 volts, there is no appreciable current in the stream when the spray nozzle is 2 ft or more from the conductor. The use of spray nozzles with long applicators or combination nozzles (solid stream or spray) is considered hazardous since their use may result in fatal electrical shock. The expressed objection to the combination nozzles is valid and should be further evaluated. In the event that it becomes necessary, it is also stated that solid streams may be used on live low voltage (600 volts or less) equipment as long as the nozzle is more than 3 ft from the equipment. It is further stated that there is no danger in the use of solid

hose streams on high voltage equipment if the stream is broken into drops before it reaches the conductor. Variables which determine the point at which the stream breaks up are stated to be the size, shape and condition of the nozzle as well as the water pressure and wind. If the solid stream strikes a high voltage conductor the amount of current flowing through the body of a person holding the conductor depends upon the voltage, the conductor, the length and cross-section of the stream, the resistivity of the water and the ratio of the resistance to ground through the persons body and the resistance to ground through the hose. The amount of current varies considerably under different conditions and may be sufficient to cause the operator to lose control of the nozzle or cause death. The use of tables that purport to show safe distance are stated to be, generally, not reliable because of the many variables.

NFPA [7] provides essentially the same information as NBEU and Factory Mutual concerning variables related to current carrying capacity of hose streams but diverges from the Factory Mutual statements concerning the use of foam by stating that foam-type extinguishing agents are very conductive. This statement further demonstrates the need to evaluate AFFF for combating electrical fires. Since this indicates that a shock hazard may result from the use of foams, the effect was evaluated by using AFFF concentrate mixed with both seawater and fresh water in several of the nozzles originally tested with seawater only. It was found that the foam provided little or no safety margin since the solutions were only slightly less conductive than seawater and more conductive than the fresh water used to dilute the AFFF concentrates. NFPA cites research on electric fences by Underwriters Laboratories Inc. which indicates that there are differences in electric current to which individuals may be safely subjected and that the maximum continuous (uninterrupted) current to which an individual may be safely subjected is 5 mA (milliamperes) ac applied on the surface of the body.

A study on the effect of impurities in water on shock hazard, conducted by the Commonwealth Edison Company for the Chicago Fire Department, is also cited in the NFPA Handbook. This study is not directly applicable to Navy shipboard fire fighting because seawater is approximately 100 fold more conductive than the Chicago river water used in the tests. It is stated that there is usually little danger to fire fighters directing streams of water onto wires of less than 600 volts at distances likely to be encountered, but cautions that danger exists at these voltages if fire fighters are standing in puddles of water or on moist surfaces come in contact with live electrical equipment.

At higher voltages safe distances ranging from 2.5 to 27 ft are prescribed by various investigators who evaluated various solid stream nozzles with tips ranging from 1/4 in. to 1-1/2 in. in diameter. The purity of water and related conductivity of the water used in these tests is not shown, but is assumed to approximate the purity of that used in the Chicago tests.

The fact that water spray reduces the conductivity hazard is supported by studies of four investigators who indicate that, at voltages up to 10,000 volts from conductor to ground, spray nozzles can be safely used at distances from 1 to 4 ft. The exact test conditions are not defined. The Edison Electric Institute is quoted as recommending minimum approach distances of 10 ft for all hand held water spray nozzles, 20 ft for 1-1/2 in. hand-held straight solid stream and 30 ft for 2-1/2 in. solid stream nozzle. (A recent incident on the USS TATTNALL [8, p. 7] involved the use of 2-1/2 in. hose lines on an electrical fire.) These recommendations are based on tests conducted by the Toledo Edison Company in which water was discharged onto a screen at a potential to ground of 80,500 volts (138 Kv line voltage). The hazard associated with the use of combination nozzles and applicators is mentioned by NFPA. The use of automatic sprinkler systems and water spray fixed systems are recommended as a means of reducing fire damage where electric or electronic equipment may be exposed. A minimum clearance of 7 in. between fixed water spray equipment and live, uninsulated electrical components for equipment operating up to 15,000 volts is specified by NFPA [9].

Navy guidance provided to fire fighters in 1947 [10] is out of date in that carbon tetrachloride, now known to be extremely toxic, was specified for use on electrical fires. Safe distances for the use of hose streams are quoted from an earlier version of the NBFU Bulletin [5] but does not include a discussion of the potential hazard due to seawater use. Otherwise the recommendations are in agreement with guidance provided above.

Current Guidance in the Naval Ships Technical Manual, Chapter 9930, Fire Fighting-Ship [11] recommends the use of carbon dioxide for Class C fires because it is a non-conductor of electricity but cautions that its use can cause suffocation. Portable CO₂ extinguishers are placed throughout the ship at strategic points. The use of solid streams (seawater) on electrical fires is prohibited because of their conductive properties and resulting hazard to fire fighters. Solid streams are not prohibited for use on electrical equipment if all equipment is disconnected and is electrically inert. The use of fog patterns is cautioned to be a last resort measure for combating electrical fires.

The Fire Chief's Handbook [2] quotes references previously cited for safe distances for the use of hose streams on electrical fires, but states that these recommendations apply only to fresh water and cautions that no rule can apply as to safe distances for solid streams if seawater is used. Information provided concerning individual resistivity is pertinent to shipboard fire fighters. The resistance to ground through a person's body may be influenced by his location (whether on wet ground or not), his skin moisture and the amount of current his body can endure are factors identified.

Tests conducted at Purdue University reported in 1936, [12], assume the resistance of the human body to be 5,000 ohms. The effects of various 60 cycle currents are estimated. It is stated that a current of 1 mA will just be felt; 4 to 10 mA, depending on the individual, will cause a sense of pain; 30 mA may cause unconsciousness and a current of 100 mA is dangerous and may be fatal. From these tests, a value of 3 mA was established as the upper safe limit for the current which may flow down the fire stream. The 5,000 ohm value for body resistance was derived from earlier experiments at Purdue conducted to support an undergraduate thesis [13]. The conductivity of water jets at higher potential were studied to explain some anomalies in the then current (1909) literature of other investigators. This literature related to the danger of electrocution incurred by a fireman in directing a stream of water through high tension electrical lines. However, it is mentioned that tests made by the National Bureau of Standards show that the resistance of the human body may be as low as 300 ohms under favorable conditions, such as encountered on naval vessels, because of the presence of water and perspiration. The Purdue investigators show minimum safe distances from high potential lines for nozzle pressures of 50 psi for 1-1/4 in. nozzles. For body resistance values of 5,000 ohms, the safe distance is shown to be 16 ft for 4,400 volt circuits. However, it is stated that the fire stream should not be allowed to strike the line if the resistance at 4,400 volts is only 500 ohms. This publication served as the principal guideline for the tests conducted for the NRL study at CBD.

Underwriters Laboratories' standard for portable hose nozzles, [14] requires that approval for Class C rating shall require that the nozzle be adjusted to the narrowest stream possible at a flow established by the maximum service pressure at which point the cone angle of the stream is measured. The minimum cone angle for approval is 30 degrees. It has been confirmed by a manufacturer of the Navy MIL-SPEC variable flow nozzle, Elkhart Brass Company, that these nozzles will not meet the UL requirement. UL lists

[15] only one adjustable flow spray nozzle which is Badger Powhatan Model 349 for use with 1-1/2 in. hose. The nozzle discharges 68 to 98 gpm at 50 to 100 psi. It is stated that use of this nozzle is not likely to prove hazardous when held at distances in excess of 10 ft from live electrical apparatus and circuits not involving voltages in excess of 250,000.

Reports of the Browns Ferry Nuclear Plant fire [16,17] indicate that the use of spray streams on energized electrical equipment is desirable. This use of water as an extinguishing agent resulted in extinguishing the fire in 10 min after unsuccessful attempts by other means for the previous 7 hours. Resulting guidance issued by the Nuclear Regulatory Commission to nuclear power plant operators in 1981 [18] is as follows:

"Experience with major electrical cable fires shows that water will promptly extinguish such fires. Since prompt extinguishing of the fire is vital to reactor safety, fire and water damage to safety systems is reduced by the more efficient application of water from fixed systems spraying directly on the fire rather than by manual application with fire hoses. Appropriate fire fighting procedures and fire training should provide the techniques, equipment, and skills for the use of water in fighting electrical cable fires in nuclear plants, particularly in areas containing a high concentration of electric cables with plastic insulation.

This is not to say that fixed water systems should be installed everywhere. Equipment that may be damaged by water should be shielded or relocated away from the fire hazard and the water. Drains should be provided to remove any water used for fire suppression and extinguishment to ensure that water accumulation does not incapacitate safety-related equipment."

Work conducted at NRL and reported by Bertschy, et al. [19], related to the development and testing of a portable water spray fire extinguisher for submarines, demonstrated a very low conductivity of the emitted spray when directed against a copper plate charged to potentials up to 950 volts. At a distance greater than 4 in., the current in all cases was less than 1 mA which is below the minimum that can be felt. Work by others, referenced in the NRL report, supports the proposition that water can be applied to energized electrical equipment under some circumstances without danger to the person holding the nozzle.

Among these references is a 1946 report by the British Admiralty [20] that included an evaluation of straight stream nozzles (branch pipes) and spray nozzles using natural seawater streams on a charged electrical device. A review of the British data revealed that, although test conditions peculiar to Royal Navy ships differed from those applicable to U.S. Navy ships in this report, both test procedures and results obtained bear a marked similarity. The British data was derived by using a 340 volt source, with a 2,000 ohm resistance to simulate that of a human body. It was noted that a decrease in nozzle pressure from 100 psi to 45 psi caused an increase in current flow at all distances where the current was measured. We found a similar effect in most of our tests which is assumed to result from lower electrical resistance in larger diameter streams provided by the lower nozzle pressures. From a practical standpoint this knowledge is of little value since the differences do not permit a change in practice. The most comprehensive report on the evaluation of lethal currents on humans was reported in the IEEE Transactions on Industry and General Applications [21]. This work is referenced by the Bureau of Standards in their report discussed earlier [3].